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# A rainfall simulator and the erodibility of some Iowa soils

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A RAINFALL SIMULATOR AND THE ERODIBILITY  
OF SOME IOWA SOILS

by

John E. Adams

A Dissertation Submitted to the  
Graduate Faculty in Partial Fulfillment of  
The Requirements for the Degree of  
DOCTOR OF PHILOSOPHY

Major Subject: Soil Physics

Approved:

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1956



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## INTRODUCTION

This study was originally sponsored by the Iowa State Conservation Commission to investigate the watershed erodibility of prospective artificial lake sites in Iowa. Watersheds which might be found to be highly erodible would not be desirable locations for future lakes unless adequate control measures could be developed prior to reservoir construction. Upon discontinuance of further reservoir construction by the Conservation Commission, the study was expanded by the Iowa Agricultural Experiment Station to measure more accurately the erodibility of Iowa soils.

Browning and co-workers (9) developed a conservation guide based on data obtained by Soil Conservation Experiment Stations located in Wisconsin, Iowa, and Missouri. This guide was used to calculate the limit of slope length for the various combinations of rotations and conservation practices which could be used on Iowa soils. Thompson (75) described a method based on Browning's data obtained at Clarinda, Iowa, by which the loss of soil in tons per acre can be calculated for a soil under various rotations and conservation practices. This method is used by students in the conservation course at Iowa State College and by farm planners in developing land use recommendations in Iowa.

The soil factor was based on the annual soil loss data for the Marshall, Shelby, and Fayette soils. Estimates were made of the comparative soil losses for the remaining important soil types in Iowa based on the physical and chemical information available. The accuracy of the soil factors for the remaining soil types would be greatly increased if the soil factors could be based on some accurate measure of erodibility.

The purpose of this study was to develop a rainfall simulator and

method which could be used in the field to make run-off, infiltration, and erosion measurements on the soil. The device developed was to be used to make measurements in the field on several different Iowa soils with all erosion factors standardized except the soil type. By use of such an instrument and method, it would be possible to make field measurements on soils in a much shorter time and at considerably less expense than by the use of run-off control plots, as has been common. Additional measurements were to be made on the soils studied of air permeability, aggregate stability, dispersion ratio, and pore size distribution. The results of these latter measurements were to be compared with the data obtained in the field with the rainfall simulator to determine the value of laboratory physical measurements in predicting soil erodibility.

## REVIEW OF LITERATURE

## Soil Erosion and Factors Affecting Soil Erosion

Soil erosion by water is a result of the destruction of soil aggregates and the dispersion of soil particles by the impact of falling raindrops, and the transporting power of the excess water as it leaves the land as run-off. Baver (4) has summarized the factors affecting soil erosion in the following descriptive equation:  $E = f(C, T, V, S, H)$ . That is, erosion is a function of climate, topography, vegetation, soils, and the human factor.

Many studies have been made of soil erosion and the factors affecting soil erosion. Baver (4 p. 349-386) brought the more important ones together in a chapter entitled "Physical Properties of Soils in Relation to Runoff and Erosion." Neal (56) gave a literature review regarding slope and rainfall characteristics in relation to run-off and erosion. Osborn (62) reviewed the existing literature on factors affecting sheet erosion. Bennett (6) presented a comprehensive literature review of studies since 1895 of raindrop characteristics, and gave a discussion of raindrop splash. This discussion was illustrated by high speed photographs at the time of impact of raindrops falling on wet soil or soil covered with a thin layer of water. Although the preceeding references have presented literature reviews on the subjects mentioned, it will be necessary to refer to some of the same articles in presenting the proper background for this study.

Ekern (21) presented a comprehensive review of the literature on the kinetic energy of natural rainfall and the soil factors affecting it. He stated that the kinetic energy for natural rainfall varies from 1,000 to 100,000 times the work capacity of shallow sheets of run-off water.

Ekern delineated the nature of the erosive features of raindrop impacting force as:  $\text{Erosivity} = f[\text{precipitation intensity} \times \text{time} \times (\text{drop mass/drop cross-section}) \times \text{drop velocity}^2]$ . He found that approximately 8 tons per acre of fine sand would be transported by the impact of drops from a rainfall of 4 in. per hr. continuing for a 5 minute period. This force distributed material over distances up to 5 feet, with a preference for downslope direction directly related to the slope per cent.

Nichols and Gray (59) stated that two inches of rain on an acre would have 194,900,000 foot-poundals or 6,000,000 foot-pounds of kinetic energy, which they calculated to be sufficient to raise a 7 inch layer of soil a height of 3 feet over an area of one acre.

Mihara (52) reported that the kinetic energy of a raindrop amounted to  $10^4$  ergs for a drop of 2 mm. radius. He stated that for a drop of 2.5 mm. radius, this corresponded to the work of raising a mass of 4.6 grams a height of 1 cm. In an ordinary shower the energy of falling raindrops was found to be about  $10^5$  ergs per sq. cm. The kinetic energy of rainfall was found to increase 1.2 times the intensity as the intensity increased. He also found that about one third of the raindrop momentum was used for the generation of spray and the remaining two thirds was dissipated as pressure against the sand surface it struck. Mihara concluded that the impact of raindrops was the main cause of sheet erosion, and suggested that precipitation be reported as kinetic energy determined from intensity rather than as amount.

Ekern (22) found that the amount of fine sand transported by drop impact increased with decreasing particle size eroded, and was directly proportional to the total mass of water supplied and to a factor representing

the energy per unit area supplied by the individual drop. The percentage transported downslope ( $D_n$ ) followed the relation  $D_n = 50 + S$ , where  $S$  = percentage of slope, which equals  $100 \tan \theta$ , and  $\theta$  = slope angle in degrees.

Ekern (22) reported that the impact energy of rainfall was a nearly identical function of intensity and slope, and that the additive energy of shallow flow and drop impact should approximate the 1.5 power of the storm intensity. He concluded that the erosivity of storms should be proportional to the additive kinetic energy from the impact of falling rain and shallow flow of water.

Borst and Woodburn (8) concluded that interference with overland flow, when plots were surface mulched, was not of great importance in reducing soil loss. Elimination of raindrop impact rather than reduction of overland flow velocity was shown to be the major contribution of the mulch. When a mulch which was supported 1 inch above the surface of a sealed plot was removed quickly during rain the soil concentration in the run-off increased 6 times. The same degree of erosion control was given by a mulch separated 1 inch above a sealed plot as when left on the surface.

Laws (40) studied drop sizes varying from 1 to 5 mm. in diameter and found that as the drop size increased, the infiltration rate decreased by as much as 70 per cent, and that erosion losses increased 1,200 per cent.

Neal (56) constructed an "impactometer" to measure and automatically record the impact of falling drops of water. It consisted, essentially, of an analytical balance beam mounted between two steel point bearings. A convex aluminum plate, 10 cm. in diameter, was mounted on one end of the beam to receive the impact of the falling drops, and a recording pen was attached to the other end of the beam. When one drop at a time fell there



was a close correlation between momentum and the deflection of the pan. However, when several drops of rain fell, there was a varying accumulation of water which made it difficult to maintain a constant base. The apparatus was never perfected further to obtain accurate results on the relative impact of artificial rains because rust formed in the steel bearings. Also, complete provision could not be made for handling the accumulation of water on and under the plate of the "impactometer".

Other factors affecting erosion, which were taken into consideration in this study, were slope and vegetation. Baver (4) listed the degree and length of slope as the essential features of topography concerned in run-off and erosion and considered the degree of slope the more important from the standpoint of erosion. Literature on the effect of slope has been comprehensively reviewed by several authors (4), (56).

Baver (4) discussed the effect of vegetation upon erosion in considerable detail and classified it into the five following categories: (a) the interception of rainfall by the vegetative canopy, (b) the decreasing of the velocity of run-off and the cutting action of water, (c) root effects in increasing granulation and porosity, (d) biological activities associated with vegetative growth and their influence on soil porosity, and (e) the transpiration of water leading to the subsequent drying out of the soil.

In 1880 Wollny (3) investigated the effect of plant cover upon the interception of rainfall and found that only 45 per cent to 88 per cent of the total rainfall reached the land surface directly, depending upon the type of crop and the number of plants per unit area.

Clark (11) found that the percentage of interception of rainfall

varied with the intensity of the rainfall, density of foliage cover, and environmental conditions. The maximum capacity of interception ranged from 47 to 261 grams of water per sq. ft. area of living plant materials; and dead plants held from 156 to 446 grams on similar areas.

Osborn (64) presented data showing that for effective control of rain-drop energy, approximately 2,000 lbs. per acre of short sod grasses, 3,500 lbs. of ordinary crops or grasses, or 6,000 lbs. of tall coarse crops and weeds were required.

#### Infiltration Studies and Infiltrimeters

Infiltration is the process involved when water enters the soil (4). Percolation is the process in which water moves through the soil. The two are not synonymous, but percolation may be involved in the process of infiltration, especially when the soil is wet. The infiltration rate is the rate at which water enters the soil. The infiltration rate is at a maximum value when water is first applied to dry soil and decreases to a stable minimum as the pore spaces become filled with water and swelling occurs. Nelson and Muckenhirn (57) called the minimum infiltration rate the field percolation rate. Conversely, as the infiltration rate decreases the run-off rate increases. The infiltration rate is affected by a number of factors. Baver (4) considers the most important factors to be the permeability of the profile, the condition of the soil surface, and the soil moisture content.

The rate at which water moves through a saturated profile is limited by the permeability and thickness of the least permeable layer. In many soils the least permeable layer is the B horizon. Nelson and Muckenhirn (57)

found that the low minimum infiltration rates, or "field percolation rates", of the Spencer silt loam and the Superior clay loam, and the high rates for Marathon and Miami silt loam could be attributed to the permeability of the  $B_2$  horizons and substrata. The immediate soil surface may be the limiting layer for many cultivated soils. Duley (16) observed the formation of a thin, compact layer at the surface of a soil and presented a number of photomicrographs clearly showing a surface crust or dense layer. Duley described an experiment with a sandy loam soil illustrating the effect of surface sealing on infiltration. When covered with straw and sprinkled at a rate in excess of intake, there was an infiltration rate of 1.2 in. per hr. at the end of five hours. With the straw removed, the intake rate dropped to 0.25 in. per hr. after 30 minutes of rain. The surface layer (about 0.3 in. thick) was removed and the plot covered with burlap. The sprinkling was repeated giving an intake rate of 1.6 in. per hr. Duley concluded that the sealing of the surface was not due to an increase of fine material but rather to the compact structure formed by the fitting of finer particles between larger ones.

Duley and Kelly (19) concluded that there might be a greater variation between rates obtained under different surface conditions on a single soil, than would be shown by different soils having the same surface conditions. They also found that the infiltration rate decreased slightly with increase in slope. Borst and Woodburn (7) found no relation between infiltration rates and slope.

Ellison and Slater (28) found infiltration rates to be highly sensitive to the quantity of soil carried by raindrop splash. Low infiltration rates were associated with large quantities of soil carried by raindrop

splash. They concluded, for the soils studied, that duration of rainfall, soil carried by raindrop splash, aggregation, and clay content of the soil were the principal factors affecting the infiltration rates.

Free, Browning, and Musgrave (32) found a definite association of infiltration with all indices of large pores, or with those factors affecting pore size. They particularly regarded "noncapillary" porosity, degree of aggregation, organic matter, and amount of clay in the subsoil as determinants of infiltration. They also found that those factors which determine the permanency of large pores, such as suspension percentage and dispersion ratio, were associated with infiltration rates.

Hendrickson (37) observed that very thin layers of silt and clay sediments applied in suspension quickly "blanketed" flat sand surfaces. The "blanket" effectively clogged the pores in such a way as to impede the movement of water into the soil-body when water was applied to the surface. He concluded that run-off waters carrying relatively small loads of fine sediment in suspension, under sheet erosion conditions, could be expected to increase erosion losses enormously for moderately erosive rains.

Neal (56) found that infiltration was not affected by either the slope or the rainfall intensity, but varied inversely as the square root of the initial soil moisture content. The initial soil moisture content had a greater effect on the rate of infiltration during the first 20 minutes than any other factor.

Tisdall (76) stated that antecedent soil moisture percentage plays an important part in the early stages of an infiltration application. He suggested the use of regression equations, obtained in his study, as a means of correcting infiltration data to a common antecedent soil moisture ten-

sion. He concluded that comparative infiltration measurements should be made when the soil is at the same moisture content or at the same moisture tension.

Smith, Brown, and Russell (72) found that increase in organic matter content by barnyard manure significantly increased the infiltration capacity of Clarion loam.

Free and Palmer (33), in a laboratory study, found that water entering closed columns of sand by gravitational and capillary movement compressed the air below the advancing moisture front. When gravitational movement ceased, strong capillary forces caused the moisture front to advance slowly until the air beneath was compressed sufficiently to effect an upward release of some air through the pores holding capillary water and the thin saturated layer at the surface. The release of air was accompanied by a marked increase in infiltration rates. The pressure necessary to cause the release of air was found to be an inverse function of the particle diameter.

Musgrave and Free (55) found that increasing the average percentage of pore space by surface cultivation markedly increased the rate of infiltration on the Marshall silt loam. They found little evidence that close vegetation increased the rate of infiltration enough to account for the marked control of surface run-off characteristic of such cover. Musgrave and Free stated that the effect of close vegetation was to reduce the velocity of surface movement and thus allow more time for infiltration to take place. They concluded that the dominant factor between the Marshall and Shelby was "soil type".

Duley and Domingo (18) applied water at temperatures ranging from 40° F to 110° F to the soil by sprinkling from a height of about 6 feet. They

concluded that it appeared doubtful if the rather narrow range in temperature likely to occur in natural rainfall would be sufficient to have any practical significance in determining the amount of rainfall that would be absorbed by agricultural land.

Baver (4) and Kohnke (39) have classed the techniques and instruments for studying infiltration into two groups: (1) Those in which infiltration rate was determined as the difference between rainfall and run-off rates and (2) those in which infiltration was assumed to be identical with the water applied and where no run-off was allowed. Both described several examples of each group.

The square-foot apparatus of Pearse and Bertleson (65) is an example of the first type. Water was applied at the uphill side of a square-foot plot (19 3/16 inches x 7 1/2 inches) in such a manner that it was spread out in a thin film as it flowed across the plot. Water absorbed or infiltrated was determined by difference between the amount applied and the run-off. A serious weakness of this method was the lateral movement of water into the drier soil surrounding the plot.

Kohnke (39) developed an infiltrometer which consisted of 16 small rectangular compartments arranged in a block, four by four, with a burette suspended over each compartment. The compartments were driven one to two inches into the ground and water applied through the burettes at the rate it enters the soil. The average of the data obtained from the four center compartments was considered as a measure of the natural local infiltration, and the outside compartments acted as a buffer between the center compartments and the outer dry soil.

Musgrave (54) developed a method in which a metal cylinder 6 inches in diameter was jacked into the soil to the B horizon. A 1,000 cc. dispensing

burette was centered over the cylinder and a perforated disk placed on top of the soil to prevent the development of turbidity when water was applied. A head of  $\frac{1}{4}$  to 5 mm. of water was maintained above the perforated disk during the measurement.

Nelson and Muckenhirn (57) used a double ring infiltrometer to make "field percolation" measurements. The inside ring was 8 inches in diameter and the outside ring 16 inches in diameter. The rings were driven 1 or 2 inches in the ground and were surrounded by a 24 inch square, made of lath. A  $\frac{1}{4}$  inch head of water was maintained on all of the enclosed areas. Water was added to the center ring by means of a 3,000 cc. burette. The authors stated that the advantages of this method over Musgrave's were the elimination of lateral movement of water, and a minimum of disturbance of soil structure as the rings were only driven 1 to 2 inches into the soil.

Cox (13) described a recording double ring infiltrometer. The diameter of the inner ring was the same as that of the top of the rain gauge used for the recording. By means of a syphon connection between the inner ring and the rain gauge float tube, the water entering the soil was recorded on the rain gauge chart. The water level for the two rings was maintained constant by means of carburetor floats. Accurate rates of infiltration were obtained by this method for periods up to 60 hours.

Rainfall simulators can be used to study infiltration, run-off or erosion, but have been more commonly used for erosion studies. Duley and Domingo (17) described a small plot procedure which they had used for studying the effects of surface condition and surface protection on the intake of water. The plot was enclosed in a rectangular open frame, 16 x 72 inches, which was forced into the soil a depth of 9 inches. A rim 3 inches high

extended above the surface on all sides except at the lower end, which was cut level with the soil surface. A rectangular metal windbreak 6 feet high was placed on top of the frame surrounding the plot. Water was forced by air pressure to a small constant-level supply tank about 3 feet above the top of the windbreak. A rubber hose with a small sprinkler nozzle at one end was attached to the bottom of the tank. Water was applied to the plot by manually swinging the nozzle back and forth across the plot from the top of the windbreak. Water striking the sides was caught in a small gutter and drained off at the lower end of the plot, where it was collected and measured. Water running off the plot itself, drained into a gutter attached to the lower end of the frame at ground level, from which it drained into a container where it was collected and measured. All measurements were taken at 200 second intervals.

Duley and Domingo found that the intake on isolated small plots having no pre-wetted border protection was 75 per cent greater than for the large plots surrounded by buffer areas. They also found that the intake of water on large plots surrounded by pre-wetted buffer areas and small plots within the large plots was similar. Duley and Domingo concluded that there had been lateral movement of moisture away from the small plots with no pre-wetted border protection, which allowed a greater intake of water.

Peele and Beale (67) described a laboratory procedure using simulated rainfall for determining infiltration rates of disturbed soil samples. The laboratory infiltrometer consisted of several small boxes for holding the soil samples, an arrangement for catching the water which percolated through the soil, and a line of so-called type-F nozzles (78) for applying the



the simulated rainfall. They found that the infiltration obtained by their laboratory infiltrometer, the type-F field infiltrometer and infiltration from natural rain storms placed the soils studied in the same order. They suggested that the laboratory infiltrometer would be useful for evaluating the effects of rotations, soil conditioners, and inherent soil properties on infiltration in the surface soil of clean cultivated areas.

Wilm (78) described and compared the following infiltrometers: (1) type-F (modified) infiltrometer, (2) Rocky Mountain infiltrometer, (3) North fork equipment, and (4) the Pearse square-foot apparatus. He found that the type-F instrument gave results higher than those obtained with the three smaller instruments, which agreed relatively well among themselves. Wilm concluded that infiltration rates are characteristically variable. Based on measured variances of adjusted averages, the largest part of this variation occurred between sites in a single plant-type and a smaller amount of variation was due to errors of instruments and techniques.

#### Run-off and Erosion Studies

A number of rainfall simulators have been constructed and used for special studies in erosion. Borst and Woodburn (7) used a "type-E" apparatus, developed by the Hydrologic Division of the Soil Conservation Service, for study on plots 72.6 feet x 6 feet or 1/100 acre in area. A canvas structure was set up over the plots with two parallel lines of pipes along each side with 21 nozzles on each pipe. The lower nozzle pipe line was 9 feet above the surface of the plot. The water was supplied to the plots through special nozzles which set up a turbulence and caused a wide lateral distribution of the spray. The drops produced were considerably smaller than

in natural rainfall of the same intensity, which, the authors suggested, may have had a different effect upon infiltration and run-off results than a natural rain. The total length of the apparatus was 80 feet and originally required 15 man-days to assemble and disassemble. It was later mounted on skids so that one side at a time could be moved by a tractor. This reduced the time to 4 or 5 man-days. Borst and Woodburn used the type-E apparatus to investigate the effect of the degree of slope on erosion and run-off. They found no significant difference in percentage and rate of run-off on slopes varying from 2.9 per cent to 22.5 per cent, but soil loss had an exponential relationship with slope, and velocity of overland flow increased exponentially with slope. On the steeper slopes, the "dry run" loss-rate tended to increase during equilibrium flow, but the "wet run" loss-rate decreased slightly. The density of run-off for the "dry runs" was not found to be significantly different from the density for the "wet runs". The difference in total soil loss was caused by differences in amount of run-off.

Craddock and Pearse (14) developed an apparatus which they called a "portable rain maker and erosion study apparatus" to study the effects of important herbaceous range cover types of the Boise River watershed on run-off and erosion. The major parts of this apparatus included a pump unit for supplying water under pressure; a sprinkler system capable of covering an area 15 feet x 50 feet; sheet metal equipment for bordering a plot 6.6 feet x 33 feet (0.005 acre) and for collecting run-off and eroded material; devices for measuring and recording the amount and rate of rainfall and run-off; and miscellaneous equipment for sampling the soil and run-off that passed through the tipping bucket run-off gauge. The sprinkler system was

a modification of the Skinner overhead irrigation system and consisted of two, 1 inch pipe lines, each 54 feet long, supported alongside the plot on surveyors tripods. It required two men one-half day to set up the complete unit and prepare for a run.

Measurements of run-off and erosion were made on 96 test plots in accordance with a standard procedure. Runs were made only when the surface soil moisture content was less than 5 per cent. Between 1.75-1.85 inches of rain was applied in 60 minutes to simulate a moderately intense storm on half of the plots and in 30 minutes to simulate a high intensity rainfall on the remaining plots.

The results of their study showed that wheatgrass range type was the most effective for watershed protection, having only 0.5 per cent run-off and 0.003 tons per acre of soil eroded. Downy chess was only moderately effective and lupine-needlegrass was of little value. The last range type, annual weed, had 60.8 per cent run-off and 7.54 tons per acre of soil eroded. They also found that doubling the rainfall intensity increased run-off one-third and erosion two-thirds and that the steepest slopes in general produced one-fifth more run-off and three and one-half times more eroded material than the gentler slopes. Analysis of variance showed that erosion was affected mostly and about equally by vegetative type and steepness of slope, and to a lesser, but significant, degree by soil disturbance and rainfall intensity.

Ellison and Pomerene (27) designed a rainfall simulator for a plot 5 x 6 feet, which Ellison has used in most of his erosion studies. Water from an overhead tank, which had 0.042 inch diameter holes drilled on 4 inch centers in the bottom, was allowed to drip on a drip screen. The drip

screen was made of chicken wire covered with cheese cloth. The cloth was allowed to sag in each opening of the wire, and short lengths of wool yarn used to guide the formation of drops hung from the cheese cloth at the center of each depression. Rainfall intensity was varied by increasing the pressure head in the tank. Drop size was controlled by using chicken wire with different sized openings and by using different sizes of wool yarn. Drop velocities were controlled by varying the height of the drip screen above the plot. Rainfall intensities varying from 4.8 to 14.8 in. per hr. could be produced with this rainfall simulator.

Basu and Puranik (1) constructed a laboratory rainfall simulator, similar to the type devised by Ellison, to be used in the study of the susceptibility of Indian soils to erosion. Water was fed from an overhead tank at a constant pressure-head, to three spherical shower heads 6 inches in diameter, having about twenty holes,  $1/32$  inch in diameter. Water from the shower heads fell on to a pair of drip screens constructed as described by Ellison and Pomerene (27), which were made to move in opposite directions while in operation. The drops fell about 7 feet to a fixed plot or soil tray 9 x 3 feet. A covered semicircular drain board was fitted below the lip of the soil tray to conduct the run-off from the soil surface to a small covered can.

The Western Gulf Region of the Soil Conservation Service conducted a field survey of soil-protective values of range cover. The results of this investigation are reported by Osborn (60, 62, 63, 64). The effectiveness of different types and amounts of cover was measured by applying artificial rainfall at the rate of 2 inches of water in 20 minutes to a 12 inch x 18 inch plot, and catching the soil and water lost by splash and run-off sepa-

rately. The water was applied by a rainfall simulator designed and constructed by the Soil Conservation Service along the basic principles and plans suggested by W. D. Ellison. Osborn (61) gave a detailed description, illustrated with photos, of the apparatus which he designated as a "mobile raindrop applicator" mounted on a one ton truck. The water supply was carried in a set of pressure tanks mounted at the front of the truck bed. A small gasoline motor and compressor developed pressure in the tanks which forced the water through a hose to the top of an enclosed tower mounted on the rear of the truck. Here it was sprayed through a nozzle onto a circular drip screen, on which the drops form on the ends of short pieces of yarn, and fell 14 feet to the ground. The nozzle and operating pressure governed the rate of water application, while the size of the yarn drippers controlled the size of the drops. Water fell uniformly over the entire circular area enclosed by the tower curtain. The test was made on a small plot 12 x 18 inches which was located in the center of the enclosed area. The plot was enclosed by a metal frame which was driven into the ground, with a minimum of disturbance to the soil and cover, so as to leave a border  $\frac{1}{2}$  inch high above the surface. Troughs were clamped tightly to the sides of the frame to receive the splash, which was intercepted by vertical splash plates 2 feet high, enclosing the plot. Surface run-off was drained into a jar by a spout at the lower edge of the plot, which was flush with the soil surface. A vacuum tank picked up the soil and water from the splash troughs and from the run-off jar through a system of suction tubes and deposited each fraction in a separate storage jar. The drops delivered had an average diameter of 5 mm. Osborn stated that in falling 14 feet the drops attained a velocity of 25 feet per second, which was 80 per cent of

the terminal velocity for this size drop according to data obtained by Laws (41). A correction factor obtained from a series of tests with a standard sand was applied to the oven-dry weight of the soil caught in the splash from each plot. Although both splash and run-off were collected, soil eroded was only determined for the splashed portion.

Osborn (60, 62) found that the effectiveness of cover was directly proportional to quantity, and that the quantity of cover was more important than the kind of cover in protecting soil from raindrop impact. Top range conditions were found to be the most favorable to water intake. Curves expressing the relationship of the effectiveness of cover in reducing splash to amounts of cover per unit area show that from 5,000 to 6,000 lbs. per acre of cover were required to provide essentially complete soil protection. Soil splash increased rapidly when the quantity of cover decreased below 2,000 to 3,000 lbs. per acre.

Measurements of soil splash on bare plots of range and crop land showed wide variations in the susceptibility of soils to movement by raindrop impact (63). In a standard test, in which the raindrop applicator had a detaching capacity of 110,000 lbs. per acre, soil movement on crop land plots ranged from 33,198 to 225,565 lbs. per acre and on range and pasture it varied from 8,832 to 160,339 lbs. per acre.

Sreenivas and co-workers (74) developed and used splash-collecting apparatus to measure soil detachment caused by artificial or natural rainfall under different soil cover conditions. They introduced the term "soil cover rating" to denote the efficiency of a soil cover in preventing soil particle detachment by falling raindrops. In the study conducted, Hubam sweetclover had a "soil cover rating" of 95.8, and buffalograss was 98.5.

$$\text{Soil cover rating} = \frac{(\text{soil splash from bare soil}) - (\text{soil splash with cover})}{\text{soil splash from bare soil}} \times 100.$$

Soil cover rating for a bare soil was zero. Sreenivas and co-workers found that the detachment of soil increased with increase in height of soil cover and decreased with increase in percentage of cover. Oat straw mulch at the rate of 2 tons per acre was found to be effective in checking detachment. Soil detachment and soil erosion were found to be closely correlated. The coefficient of correlation between them was 0.975.

Free (31) described a technique for studying the effects of natural rain under controlled conditions. He found that for surface soils the average loss per inch of rain varied from 5 to 7 tons per acre; "splash" losses were 50 to 90 times "wash-off" losses; wash-off from slopes facing the storm were 3 times those facing away from its direction. He concluded that wash-off losses appeared to be more closely related to the field behavior of soils and provided a better index of the erosiveness of storms than did splash loss.

Laws and Parsons (42) found that the median drop size appeared to be a fairly strict function of rainfall intensity, and that the upper limit of drop size for intense rains was about seven mm. in diameter. They stated that the erosive power of intense rainfall per unit-volume will be greater, because of the larger drop-size, than the erosive power of low-intensity rains.

Ellison (23), in experimental studies of raindrop splash, reported a maximum distance of splash of 5 ft. when using a drop size of 5.1 mm. and a drop velocity of 18 ft. per sec. Some stone fragments as large as 4 mm. were splashed 8 inches, and soil aggregates and particles 2 mm. were moved

as far as 16 inches. Changing the drop size to 3.6 mm. and drop velocity to about 17 ft. per sec., reduced the maximum splash distance to 3.5 feet. Results from this study also showed that the samples of splash contained a greater percentage of aggregates smaller than 0.105 mm. than the original soil, indicating a breaking down of the aggregates under raindrop impact. From this study Ellison concluded that there are three distinct actions in the raindrop erosion process. These are: (a) the breaking down of soil aggregates, (b) displacement and transportation of the soils, (c) making the water turbid with suspended material which reduced infiltration.

Ellison (24) suggested that the storm energy dissipated on the soil be determined by measuring the soil carried in the raindrop splash. His basis for this suggestion was the fact that an increase in drop impact or number of drops caused an increase in the amount of soil splashed. Ellison also found that a variation in either drop size or drop velocity caused a change in the infiltration-rate of the soil. Changes in drop-velocity had the greatest effect, changes in drop-size were second, and changes in rainfall-intensity were least effective.

Ellison (25) stated that the quantity of soil detached will be proportional to the detaching capacity of the falling raindrops and the detachability of the soil, which he showed in the following equation:  $D_1 = D_2 \times D_3$ , where  $D_1$  = the detachment hazard or the amount of soil detached by splash,  $D_2$  = the detachability of the soil, and  $D_3$  = detaching capacity of the rain or the total impact of the drops. He modified the equation to show the effectiveness of vegetation in absorbing part of the raindrop energy as follows:  $R$  = the impact-conditioning factor of the vegetation and  $D_1 = \frac{D_2 \times D_3}{R}$ . Ellison also discussed methods of determining the factors of his



erosion equation.

Ellison (26) combined the factors that affect soil transportation by splash on a standard surface into the equation:  $T_1 = f(T_2, T_3, D_1)$  where  $T_1$  = the transportation hazard;  $T_2$  = the transportability of the soil;  $T_3$  = the capacity of the transporting agent;  $D_1$  = soil detached by splash. The methods of determining the factors were discussed but no data were presented.

#### Air Permeability and Aeration Pore Space

The minimum infiltration rate of soil has been referred to as the field percolation rate and is affected by the properties of the entire profile. The rate at which the water will move through a profile is dependent upon the size of the channels or pores, and increases with pore size. Earlier workers referred to these larger pores as "non-capillary" pores and the smaller pores as "capillary". Baver (2, 4) refers to the "non-capillary" porosity as being from zero tension to the flex point of the pF-moisture curve, as it appeared to be closely associated with the rate of water movement through a column. Baver observed that the tension of the flex-point in the moisture-pF curve seemed to be closely related to permeability, with the rate of percolation increasing as the pF of the flex point decreased. Baver (4) stated that soil permeability is dependent upon the non-capillary porosity, if the tension at which this porosity is determined is chosen correctly. The fact that the term "non-capillary" porosity has never been defined in terms of tension or pore size has led to considerable confusion in its use. Baver recognized this limitation and stated that in most cases saturation would include all those pores that will lift water at least 10 cm. Baver also pointed out that there was a lack of uniformity in the

methods of establishing the moisture tension for saturating the capillary pores. In some methods the soil is saturated by capillarity from a free water surface; in other methods the moisture content at field capacity is used; and in some methods the soil is placed on a layer of sand several centimeters above the water level.

Nelson and Baver (58) found a better correlation between pores drained at pF 1.6 ( a tension of 40 cm. of water) and the percolation rate than at any other tension. They suggested, that where only one tension was to be used, that 40 cm. of water (pF 1.6) would be the logical tension to get the most information on the water and air permeability of a soil.

Smith and co-workers (73) found a relationship between percolation rates and effective pore-size distribution that was best expressed in the following porosity factor:  $\frac{\% \text{ pores drained at 10 cm.}}{1} + \frac{\% \text{ pores drained between 10-40 cm.}}{4}$   
 $+ \frac{\% \text{ pores drained between 40-100 cm.}}{10}$  They stated that pores drained at 40 to 100 cm. tension made very small contributions to percolation and could be omitted except for soils with very slow rates.

Bendixen and Slater (5) suggested a time-of-drainage procedure of one hour at 60 cm. of tension for determining the permeability of soils under tension flow. This type of determination was suggested to support soil survey characterizations of permeability rather than as an exact measure of permeability.

Leamer and Shaw (44) described a simple apparatus for the rapid determination of "noncapillary" pore space.

More recent trends seem to be toward making complete moisture retention curves rather than use of a single tension. From this information,

pore-size distribution can be determined by a method as described by Leamer and Lutz (43). Leamer and Lutz stated that percolation and aeration in soils were dependent upon the size rather than the amount of pore space, and that not all soils, even of the same mechanical composition, have the same sized pores.

It is generally agreed that the percolation of water through a soil column is definitely a function of the amount and size of the large pores. Experimental evidence (4) seems to suggest that the factors of porosity that limit air permeability are similar to those affecting water movement. Therefore, air permeability data should help one to predict how fast water will move through the profile.

Buehrer (10), in investigations on the flow of air through lead shot, showed that air permeability varied directly as the square of the average diameter of the particle. In other words, as the size of the pores increased, permeability became greater. Buehrer proposed a quantitative definition of soil structure in terms of the flow of air, or air permeability. He calculated a constant from the flow equation on the basis of experimental data which he designated as a "structure constant". The "structure constant" was found to vary from soil to soil and decreased very markedly with successive additions in percentage of the finer constituent. After about 30 per cent of fine material had been added, it gradually decreased to zero.

Dobryakov (15) described a method for measuring soil structure by determining the rate of intake of air under constant pressure into the soil before and after moistening. Measurements were made at 5, 15, 30, and 60 minutes after the application of water, as well as just before.

He proposed a structural classification based on the air permeability results obtained 60 minutes after moistening the soil with a definite quantity of water. By this method Dobryakov found it possible to measure the capacity of a soil to recover its air permeability in a given time. He rated the compaction and structural makeup of several Russian soils based on permeability measurements made by this method. The initial moisture content of the soil, while measured, is apparently not at a standard moisture content and the pressure used in the apparatus is not given. This makes the method difficult to evaluate and it is possible that the initial soil moisture content may have had an influence which was not considered.

Grover (35) recently devised a simplified air permeameter which incorporated the features of a gasometer. The rate of fall of a float, under about 3 cm. water pressure, was used to calculate the air permeability of the soil in absolute units ( $\mu^2$ ).

#### Aggregation

One would expect a soil that is well aggregated to be able to take in more water and therefore to be less erodible than a soil which has a low percentage of water stable aggregates. A soil with a large amount of water stable aggregates would be expected to have a high infiltration rate because of an open surface with no surface sealing; water that entered the soil should drain through the profile rapidly because of the larger pore spaces.

Lutz (47) found the "non-erosive" nature of the Davidson clay was largely due to the high degree of aggregation of the B horizon into large porous stable granules; the erosiveness of the Iredell was due to its ease

of dispersion and the dense, impervious B horizon.

Elson and Lutz (29) investigated the relation between aggregation and erosion and concluded that better aggregation resulted in less soil erosion. Lillard and co-workers (45) found that the extent to which the silt and clay was aggregated in the surface soil of a Dunmore silt loam appeared to have more influence on erodibility than the physical nature of the subsoil.

Rai, Raney, and Vanderford (68) subjected aggregates of various sizes, obtained by treating montmorillonitic clay with a vinyl acetate-maleic acid, to simulated rain falling 7 feet. They found that the intensity of soil erosion progressively increased as aggregate size decreased from 1,000 to 500  $\mu$  and less. The erosion study was limited to the situation where the soil was fully saturated and at zero infiltration.

In most aggregate studies some modification of the Yoder (81) method of aggregate analysis is used. In many methods the soil sample is allowed to become air dry before testing, as recommended by Yoder. McCalla (49) devised a method of determining the stability of soil structure in which water drops 4.7 mm. in diameter fall a distance of 30 cm. on a lump of soil weighing about 0.15 gm. He concluded that the action of the falling water drop on structure was largely through wetting and swelling which loosened up the lump so that a drop could disintegrate the structure.

Johnston, Browning, and Russell (38) found that the size distribution of soil aggregates was influenced by the cropping system, with the number of large sized aggregates being in the order Bluegrass > Clover > oats > rotation corn > continuous corn. The average annual soil loss in tons per acre was 39.3, 19.2, 10.7, 0.11, and 0.02 from continuous corn, rotation corn, oats, red clover and bluegrass respectively. Wilson and Browning

(79) found the percentage aggregates greater than 0.25 mm. for different crops to be in the order: continuous corn < rotation corn < rotation clover < continuous alfalfa < continuous bluegrass. The order was reversed for soil loss and run-off. The percentage aggregates greater than 0.25 mm. decreased, and soil and water losses increased, with each successive year of corn following 11 years of alfalfa or bluegrass. Wilson, Gish and Browning (80) found the percentage aggregates greater than 2 mm. to be higher in August than in May or November. Continuous corn had the lowest content of aggregates greater than 2 mm. and continuous bluegrass had the highest content. The percentage of aggregates greater than 2 mm. under different crops was in the order continuous bluegrass > rotation meadow > rotation corn > continuous corn.

Gish and Browning (34) found on the Marshall, Belinda, and Clarion soils, that aggregation under four rotations decreased in the order: continuous corn < rotation corn < rotation meadow < bluegrass. For the same soils the number of large stable aggregates increased from spring to a peak in midsummer and then declined gradually throughout the remainder of the growing season. They also observed that the moisture content of the soil at the time of sampling influenced the amount and stability of soil aggregates. A Marshall loam under continuous bluegrass was found to contain 42.8 per cent, 25.5 per cent, and 28.5 per cent of the total soil in aggregates greater than 2 mm. when the moisture content of the soil was 6.5 per cent, 14.4 per cent, and 21.6 per cent respectively.

Rost and Rowles (70) suggested the aggregation ratio as an index of aggregate stability. This ratio was determined in the same manner as the dispersion ratio (51) except that the soil was allowed to slake for 24

hours. Instead of calculating the amount of silt and clay which was dispersed, the per cent aggregated into particles greater than 0.05 mm. in diameter was determined.

### Erosion Indices

Middleton (51) was one of the first soil scientists to try to obtain an index of erodibility of soils based on the physical properties of the soil. As a result of a study of the properties of soils which influence erosion, Middleton considered that the outstanding characteristics which differentiated soils with respect to erosion were the dispersion ratio, ratio of colloid to moisture equivalent, and erosion ratio. He considered the dispersion ratio as the most valuable single criterion and suggested that soils with a dispersion ratio less than 15 be classed as non-erosive. Middleton defined the dispersion ratio as the ratio of silt and clay in a non-dispersed mechanical analysis to the silt and clay in a dispersed mechanical analysis. The erosion ratio was defined as the quotient obtained by dividing the dispersion ratio by the ratio of the colloid to the moisture equivalent. The dispersion ratio is a function of the ease of dispersion and of the mechanical composition of the soil.

Cook (12) suggested that an "erodibility index" or a measure of erodibility be developed, based on some type of field test or measurement. He suggested as a field measurement, the use of a standard plot of small dimensions to which a fixed quantity of water should be applied by a standardized artificial rainfall or by flowing across the surface at a fixed rate. The amount of erosion obtained by such a measurement would be used to set up an "erodibility index".

Peele (66) thought the percolation rate, suspension percentage, and dispersion ratio were good indices of the relative erodibility of soils, and that the rate at which water percolates through a soil was a more accurate index of the susceptibility of a soil to erosion than its water-holding capacity.

Rost and Rowles (70) found under Minnesota conditions that cultivated soils with dispersion and erosion ratios of less than 19 could be expected to be resistant to erosion.

Basu and Puranik (1) constructed a rainfall simulator to be used in studying the susceptibility of Indian soils toward erosion, and for classifying the soils from the point of their erodibility index. They planned to collect data on the erosional behavior of soils with respect to the percentage run-off and loss of soil at different moisture levels, soil surface conditions, and slopes, by the controlled simulation of rain of different intensities. They hope ultimately to interlink their results on the various factors into a mathematical equation to be used in interpreting the significance of soil factors in the catchment characteristics for soil erosion.

Voznesensky and Artsruui (77) developed an equation or formula for an index of erodibility based on physical properties which may be studied in the laboratory. They proposed the formula  $E = \frac{d \cdot h}{a}$  in which E = index of erodibility, d = index of dispersion, h = index of water-retaining capacity, and a = index of aggregation. The index of dispersion "d" was the ratio of the quantity of soil less than 0.05 mm. in diameter obtained by pipette analysis after dispersion by boiling for one hour and shaking two hours, to the quantity obtained after chemical dispersion, boiling for one hour and shaking for three hours. The index of water-retaining capacity "h" was



the quantity of water held by one gram of soil colloids under experimental conditions. The index of aggregation "a" was the quantity of water-stable aggregates greater than 0.25 mm. diameter per unit weight of soil. The index of erodibility values obtained in this way for five soils was said to reflect the observed differences in the erodibility of the main genetic types of the Caucasian foothills. Arid soils were found to be the most erodible.

Gussak (36) developed a flume to measure the erodibility of soils based on the volume of water required to wash away 100 cc. of soil by a surface stream of varying velocity. A linear relationship was found to exist between the erodibility of the soil and the rate of flow. He found that at a flow of 5 cc. per sec. a chernozem was ten times as stable as a drift loam, but that at 11 cc. per sec. the drift soil was the more stable. Gussak considered erosion strictly as a result of surface run-off and completely ignored the action of the falling raindrops in soil erosion.

Browning et al. (9) developed a conservation guide for all soils mapped in Iowa, to be used in calculating the limit of the slope length for various combinations of rotations and conservation practices.

Thompson (75 p. 317-321) described a method based on Browning's data obtained at Clarinda, in which the soil loss in tons per acre was calculated for a soil under various rotations and conservation practices.

The method of Browning et al. (9) and that described by Thompson (75 p. 317-321) are discussed in greater detail in connection with the data obtained in this investigation.

## METHODS OF INVESTIGATIONS

## Infiltrometer Design and Construction

Rainfall simulators previously described in the literature have been large and bulky, and were either designed to be used in a fixed position in the laboratory or to be set up over a rather large plot in the field. Most of the rainfall simulators had either pressure tanks to lift the water 7 to 14 feet above the area to be wetted or were connected to a water supply with sufficient pressure to lift the water the desired height. Pressure tanks and containers to supply the water for plots usually occupied considerable space. In addition to requiring much space, several people were required to set up and operate such infiltrometers in the field.

For the purpose of this investigation, it was decided that the rainfall simulator should be small enough for one person to install and operate. In most rainfall simulators heretofore used the water has either been applied as a spray from a nozzle or drops from wool yarn. Neither of these methods was considered as feasible for a small rainfall simulator. Mamisao (48) designed a laboratory rainfall simulator which used glass capillary tubes with a copper wire inserted through them to form drops. With the tubes spaced  $2\frac{1}{2}$  inches between centers, Mamisao was able to obtain delivery rates of from 3.84 in. per hr. to 17 in. per hr. by varying the pressure head from 0.98 to 35.92 inches of water. This method of applying water appeared to have advantages for applying water in the field, as broken tubes could be quickly and easily replaced and the unit would be easy to clean by removing the wires and flushing the capillary tubes. Capillary tubes were used in the present equipment.

### Rainfall simulator<sup>1</sup>

The rainfall simulator (Figures 1 and 2) consisted of the following component parts: splash shield (N), wind shield (O), supply tank (P) containing raindrop applicators (Q), water reservoir (R), and head regulator (S). The rainfall simulator was supported on the run-off trough in such a manner that when completely assembled, the supply tank containing the raindrop applicator tubes was centered directly over the infiltration cylinder. The infiltration cylinder was leveled at the time of installation, by checking with a carpenters level, to insure that no drops would fall directly into the run-off trough. If one side of the infiltration cylinder was 0.042 inch out of level, the outside drops would fall in the run-off trough on one side while the soil surface on the opposite side of the infiltration cylinder would receive no drops.

In constructing the equipment, all contacting surfaces were machined so that the raindrop applicators would be centered over the infiltration cylinder when the apparatus was assembled. The wind shield and splash shield were made separate so that soil splashed against the sides, along with the soil in the run-off trough, could be washed into a "milk bottle" (T).

The splash shield was made from brass tubing with  $1/8$  inch wall,  $7\frac{1}{2}$  inches O.D. and 6 inches high, with both upper and lower surfaces machined. After many of the runs, splash was noticed on the lower part of the wind shield for a distance of 4 to 6 inches above the splash shield. It is suggested that for future determinations the splash shield should be made

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<sup>1</sup>The rainfall simulator and other special equipment were constructed by Lyle Anderson and Clarence Haughsted, machinists of the chemistry shop, Iowa State College, who also made many helpful suggestions regarding the construction of the equipment.

Figure 1. Assembly drawing showing constructional details of the air permeameter, infiltration cylinder, and rainfall simulator. Broken lines across drawing indicate diagramatic compression.

Legend:

A = Air chamber	I = Inner annular water tank	Q = Raindrop applicators
B = Infiltration cylinder	J = Small float	R = Water reservoir
C = Run-off trough	K = Float guide tube	S = Head control tube
D = O-ring shoulder	L = Float guide rod	T = Milk bottle
E = Rubber O-ring	M = Run-off spout	U = Metal guides
F = Manometer tube	N = Splash shield	V = Cavity filled with Castolite
G = Air inlet valve	O = Wind shield	W = Plexiglas reservoir and regulator holder
H = Outer annular water tank	P = Supply tank	X = Reservoir support

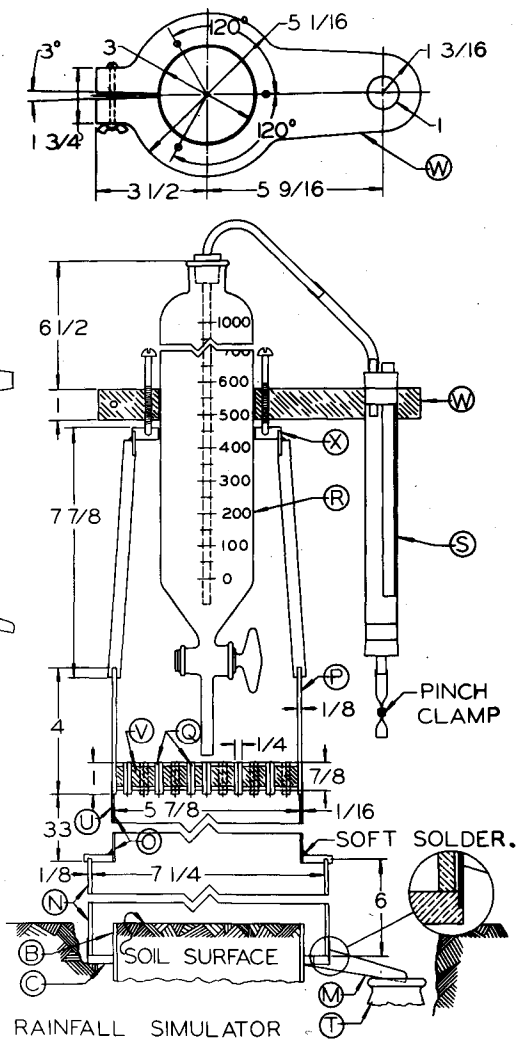
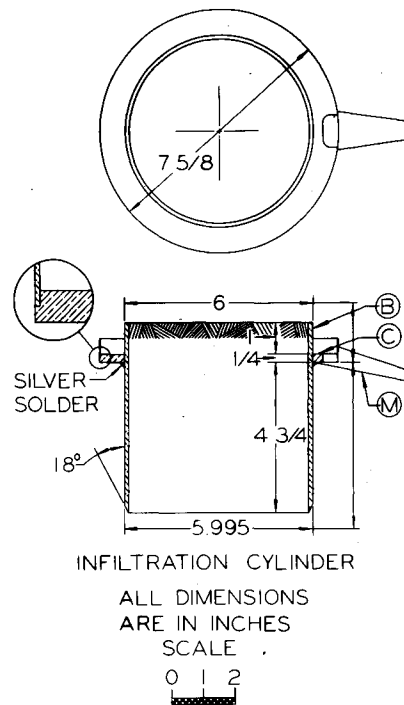
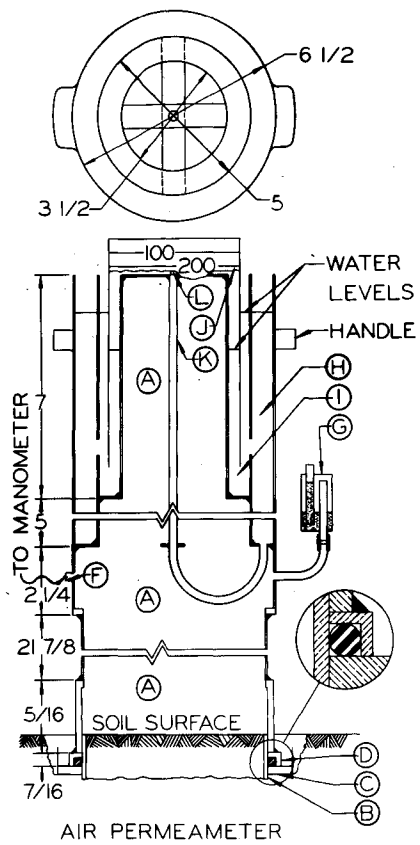
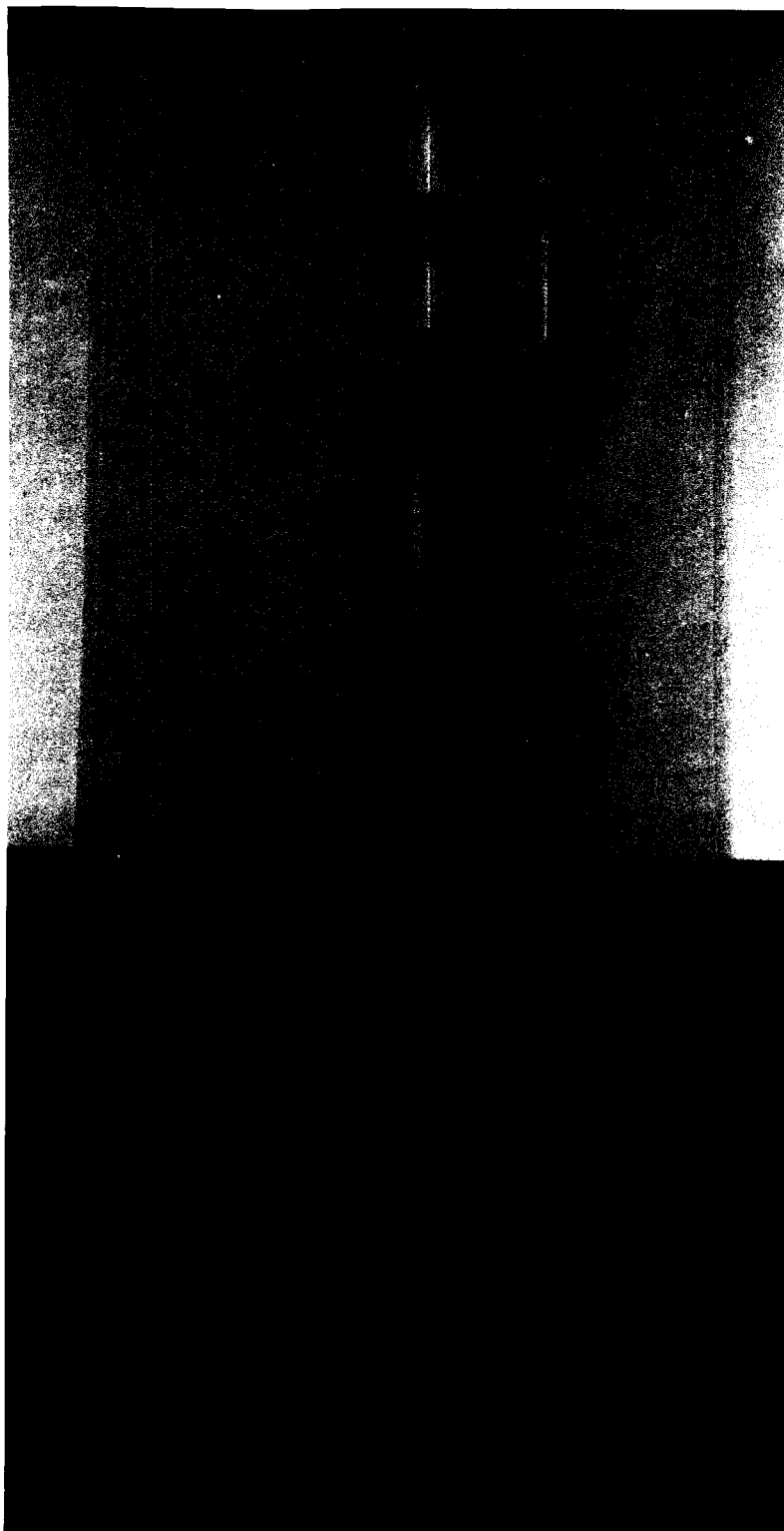


Figure 2. Rainfall simulator assembled on an infiltration cylinder.



12 inches high.

The wind shield was made from 6 inch O. D., 1/16 inch wall brass tubing and had a  $\frac{1}{4}$  inch brass ring, soft soldered to the lower end. The brass ring was grooved to center the wind shield over the infiltration cylinder when mounted on the splash shield. Three metal guides (U) were soft soldered to the upper portion of the wind shield to hold the water supply tank in place.

The water supply tank was constructed from 6 inch O. D., 1/8 inch wall brass tubing. The raindrop applicators consisted of  $\frac{1}{4}$  inch O. D. glass capillary tubing, with about 1.2 mm. bore (0.060 in.) and had Chromel "A" wire<sup>1</sup>, 0.040 inch in diameter, supported in the capillary, which caused the water to fall as drops. The capillary tubes were cut on a glass cutting wheel so that the ends were flat and at right angles to the outer wall. Each capillary tube used was checked with a standard wire for delivery rate and only those tubes were used which delivered 5 drops in a 20 to 25 second interval, when a constant head of 6  $\frac{3}{4}$  inches was maintained. The base of the water supply tank consisted of two circular brass plates  $\frac{1}{4}$  inch thick, mounted  $\frac{3}{4}$  inch apart. A  $\frac{1}{4}$  inch-diameter hole was drilled through the center of the base and 99 holes  $\frac{1}{4}$  inch-diameter were drilled in five concentric circles spaced  $\frac{1}{2}$  inch apart. The 1 inch capillary tubes were inserted in the holes through the two plates and held in place, temporarily, with Duco cement. The cavity (V) between the two plates was filled with liquid castolite which soon hardened and permanently sealed the tubes in place.

The water reservoir consisted of a 1 liter graduated cylindrical separatory funnel with 10 ml. subdivisions, and was connected to the head reg-

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<sup>1</sup>Manufactured by Haskins Manufacturing Company, Lawton Ave. and Buchanan Street, Detroit 8, Michigan.



ulator which was made from 1 inch O. D. Plexiglas tubing. Both were mounted in a plexiglas holder (W) that sat on a reservoir support (X), which was a special steel ring stand with legs grooved to set on the upper edge of the water supply tank.

When assembled and in operation the rainfall simulator delivered drops which averaged 5.56 mm. in diameter. The kinetic energy developed by a raindrop 5.56 mm. in diameter and falling one meter, was found to be equivalent to that developed by a raindrop of 3.44 mm. falling at terminal velocity, which is in the range of the median diameter drop size for a rainfall intensity of 4.0 inches per hour (21).

#### Air permeameter

Air permeability measurements were made with a permeameter (Figures 1 and 3) having an air chamber of the gasometer type described by Grover (35). A modification<sup>1</sup> was used in which the air chamber (A) was placed immediately above the infiltration cylinder (B) and air was forced directly into the soil.

The finished permeameter differed from Grover's in several ways. The base of the permeameter air chamber (A) was made so that it would slip over the top of the infiltration cylinder (B) and rest on the run-off trough (C). A shoulder (D) on the lower edge of the air chamber sealed against a  $\frac{1}{4}$  inch thick, 6 inch I. D. rubber O-ring (E) to form an air seal between the air chamber and the run-off trough. As an additional seal, and to aid in detecting air leaks during an air permeability measurement, the run-off spout (M) was plugged with "Absorene" brand non-crumbly type wallpaper

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<sup>1</sup>Suggested by J. F. Stone.

Figure 3. Air permeability measurement being made on Clarion silt loam using large float. Several plots, covered with insulation paper, can be seen in the background.



cleaner and the run-off trough filled with water.

A manometer tube (F) and air inlet valve (G) were located in the upper portion of the air chamber, below the outer annular water tank (H). A manually operated stop-cock was the air-inlet valve on the permeameter used in collecting the field data, although the drawing in Figure 1 shows the combination manometer, air-inlet valve described by Grover.

Two different sized interconnected annular water tanks were located at the upper part of the permeameter, partially covering and enclosing the upper portion of the air chamber. The inner annular water tank (I) was designed for use with a small float (J), graduated in 100 ml. subdivisions, which was used for slowly permeable soils; the outer annular water tank (H) was for use with a larger float having 500 ml. subdivisions for more permeable soils. The small float was made for a Superoxol can and the large float from a can in which technical grade sodium hydroxide is shipped. Both floats were counter-balanced so as to have a pressure per unit area of approximately 3 cm. of water. The float guide tube (K) was held in place by a narrow support across both the top and bottom of the water tanks, and was connected to the outer annular water tank so as to provide lubrication between the guide tube and float guide rod (L). The tops of the water tanks were used as the indices from which to measure the distance per unit time that the floats fell. The air chamber was extended in height, so that the tops of the water tanks were three feet above the ground, to facilitate reading the floats.

The permeameter was made entirely from brass plate or tubing except for the floats and the extended part of the air chamber, which was made from 6 inch I. D. 1/16 inch wall seamless steel tubing. All metal surfaces

were coated with Ford Motor Company brand Chrome Saver to prevent rust. All joints and connections were soft soldered.

#### Infiltration cylinder

The infiltration cylinder was 6 inches long and was constructed from 6 inch O. D. brass tubing with 1/8 inch wall. The lower edge was beveled on the outside at an angle of about  $18^{\circ}$  to form a cutting edge. The lower 5 inches of the cylinder was machined down 0.005 inch and a circular piece of  $\frac{1}{4}$  inch brass plate 13/16 inch wide (with an I. D. the same as the O. D. of the machined portion of the cylinder) was forced against the shoulder of the unmachined portion of the cylinder and silver soldered in place. A rim, cut from 1/32 inch brass plate was silver soldered on the outside of the plate, forming the run-off trough, and a spout of similar material was soft soldered to the plate and rim for the run-off spout (M).

The infiltration cylinders were installed by a special 7 pound steel hammer which was moved up and down on a steel rod attached to a steel plate. The steel plate was machined so that it fitted over the edge of the infiltration cylinder. The infiltration cylinders were forced in the ground by driving the hammer against the steel plate repeatedly.

#### Field Investigation

In order to evaluate the soil factor, or the factor in soil erosion attributed to different soil types, it is essential that all the other factors of erosion be maintained at a constant level. It was decided to maintain the factors of rainfall, slope, cropping history, soil surface condition and initial moisture level of the soil as uniformly as possible under field conditions. Other factors affecting the erodibility of a soil, such as aggregate

stability, aeration pore space, and field percolation rate, were beyond control and were considered as part of the properties constituting the soil factor. Therefore, the following conditions were to be maintained for each soil studied:

1. Rainfall. Intensity of 4 inches per hour  $\pm$  10 per cent and a total rain of 2.00<sup>1</sup> inches ( $\frac{1}{2}$  hour duration of rain).

2. Slope. Zero per cent slope was to be maintained. The infiltration cylinder was checked for level by use of a carpenters level.

3. Cropping history. All sites were to be in the fall of the oat phase of a corn, corn, oat, meadow (C-C-O-M) rotation.

4. Initial moisture level. All infiltration and run-off determinations were to be made with the soil at field capacity. An excess of water was added to each plot to be studied and field capacity was considered as being that moisture level equilibrium attained after standing 24 hours for the coarser textured soils, 48 hours for the intermediate textured soils, and 72 hours after for the finer textured soils.

5. Soil surface condition. To be loosened to a depth of  $\frac{1}{2}$  inch prior to soaking the soil to bring it to field capacity.

The rainfall intensity of 4 in. per hr. was selected as a rate which was sufficient to produce erosion and which occurred in the area studied. Information obtained from integrated histograms on intensity-time duration rainfalls prepared by Engelbrecht (30) showed that in the last twenty-two years, twenty-five, 5 minute duration rainfalls had occurred with intensities of 3.6 to 4.8 in. per hr. and seven with intensities varying from 4.8 to 6.0 in. per hr. During the same period ten, 10 minute duration rainfalls

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<sup>1</sup>The average quantity applied was actually 2.01 inches.

varying from 3.6 to 4.8 in. per hr., and eight, 15 minute duration rain-falls varying from 3.2 to 4.0 in. per hr. had occurred. This information was prepared from Weather Bureau data collected for Des Moines, Iowa. Maximum 30 minute precipitation (70) for the area within which the studies were conducted, has approached or exceeded 2 inches as shown for the following points:

Des Moines, Iowa = 1.91 inches

Omaha, Nebraska = 2.32 inches

Sioux City, Iowa = 2.73 inches

La Cross, Wisconsin = 1.99 inches

Keokuk, Iowa = 1.95 inches

#### Soils and sites studied

Eight soils were selected to be studied ranging in texture from a loamy fine sand to a silty clay loam. A textural variation in soils was desired to help provide maximum contrast of the data to be obtained. The soils selected for study and their locations are given in Table 1.

The descriptions of these soils, as taken from the "Established and Tentative Soil Series of the United States"<sup>1</sup>, Soil Conservation Service, Division of Soil Survey, are given in Appendix I.

The sites to be studied were located, tentatively, by a preliminary survey from the road to find fields which were in the rotation desired, and a more detailed inspection by auger was made in the field. Identification of all soils studied was established by Dr. Wayne Scholtes, Professor of Soils, who located the sites to be studied.

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<sup>1</sup>These were supplied by Dr. W. H. Scholtes, Agronomy Department, Iowa State College, Ames, Iowa.

Table 1. Soils and locations of sites studied.

Soil type	Location	Farm Operator
Clarion loam	1½ miles E of Ames NW ¼ SW ¼ Sec. 31, T84N, R 23 W	Albert Woods
Webster silty clay loam	Rotation plots, Iowa State College Agronomy Farm, Ames, Iowa	
Thurman loamy fine sand	1 mile E of Ames NE ¼ SW ¼ Sec. 12, T83N, R 24 W	Carl Sampson
Marshall silt loam <sup>1</sup>	Rotation plots, Clarinda Expt. Station farm	
Ida silt loam	SE ¼ SE ¼ Sec. 7, T83N, R 43 W	F. D. Mings
Monona silt loam <sup>1</sup>	Near Western Iowa Expt. Farm NW corner NW ¼ NW ¼ Sec. 27, T84N, R 43 W	K. H. Witzel
Grundy silty clay loam	Near Beaconsfield, Iowa SW ¼ Sec. 26 T70N R 28 W	Riley McAlexander
Shelby loam	Near Beaconsfield, Iowa SW ¼ Sec. 26 T70N R 28 W	Riley McAlexander

<sup>1</sup>Most of A horizon appeared to have been removed by erosion.



Six of the soils studies were on privately owned land rather than rotation plots supervised by the Iowa Agricultural Experiment Station. Rotation plots were not used on all soils studied because the working area required was as large as or larger than most of the plots, and there was the possibility that such activity might damage the plot and carry some effect over into the next year of the rotation.

#### Field operating procedure

After the soil was located in the fall of the oat phase of the rotation, a 21 foot by 9 foot rectangle was staked out on an area which had as little slope as possible. The rectangular area was then subdivided into twenty-one squares, with sides of 3 feet, which were designated as plots. The plots were numbered from left to right, starting with number one as the southeast plot when the long axis of the area ran from east to west, and with the southwest plot when the long axis ran north and south. Ten numbers were drawn at random to select the plots in which the measurements were to be made. The vegetation standing on the plots selected was clipped at the soil surface and all extraneous material removed from the surface of the plot. An infiltration cylinder was placed near the center of each plot selected, making certain that the cutting edge of the cylinder did not rest on, or next to, the root of any of the legumes which had been clipped.

The cylinder was then forced about 3 inches into the soil by means of the special hammer or driver previously described. Soil was then removed to a depth of about  $1\frac{1}{2}$  inches to make space for the run-off trough. A small mason's trowel, sharpened on two edges, was used for removing the soil from around the infiltration cylinder and for cutting a cavity for the run-off spout. The infiltration cylinder was then forced into the soil

until the top was even with the soil surface. The cylinder was kept as nearly vertical as possible during installation, by guiding it with the rod on which the hammer slid. The soil surface within the infiltration cylinder was trimmed to a flat surface with the edge of the trowel before the cylinder was finally leveled. A galvanized sheet metal cylinder, eighteen inches in diameter and eight inches deep, was used as an outside retaining wall to pond water over the infiltration cylinder. This larger cylinder was installed with the infiltration cylinder in its center, and was forced about four inches into the soil. After the larger cylinder was installed, all of the soil surface enclosed, including the area within the infiltration cylinder, was loosened to a depth of about  $\frac{1}{2}$  inch. A rake-like device, which consisted of a piece of plywood  $\frac{1}{4}$  inches x  $\frac{3}{4}$  inches, with small finishing nails protruding  $\frac{5}{16}$  inch, was used to loosen the soil surface by a series of scratching and picking motions. Two burlap bags were then placed over the soil surface and 5 gallons of water was added in such a manner as not to cause turbulence or washing of the soil surface. This quantity of water was sufficient to wet the soils studied to field capacity to a depth of at least two feet. The burlap bags were removed and a 2 foot square of aluminum insulation paper was tied over the outer cylinder, and the installation allowed to stand until the added water had drained to a moisture tension near field capacity. The Thurman was allowed to drain for twenty-four hours, the Webster, Grundy and Shelby were allowed to drain for seventy-two hours, and the remaining soils were allowed to drain for forty-eight hours.

#### Infiltration and run-off determination

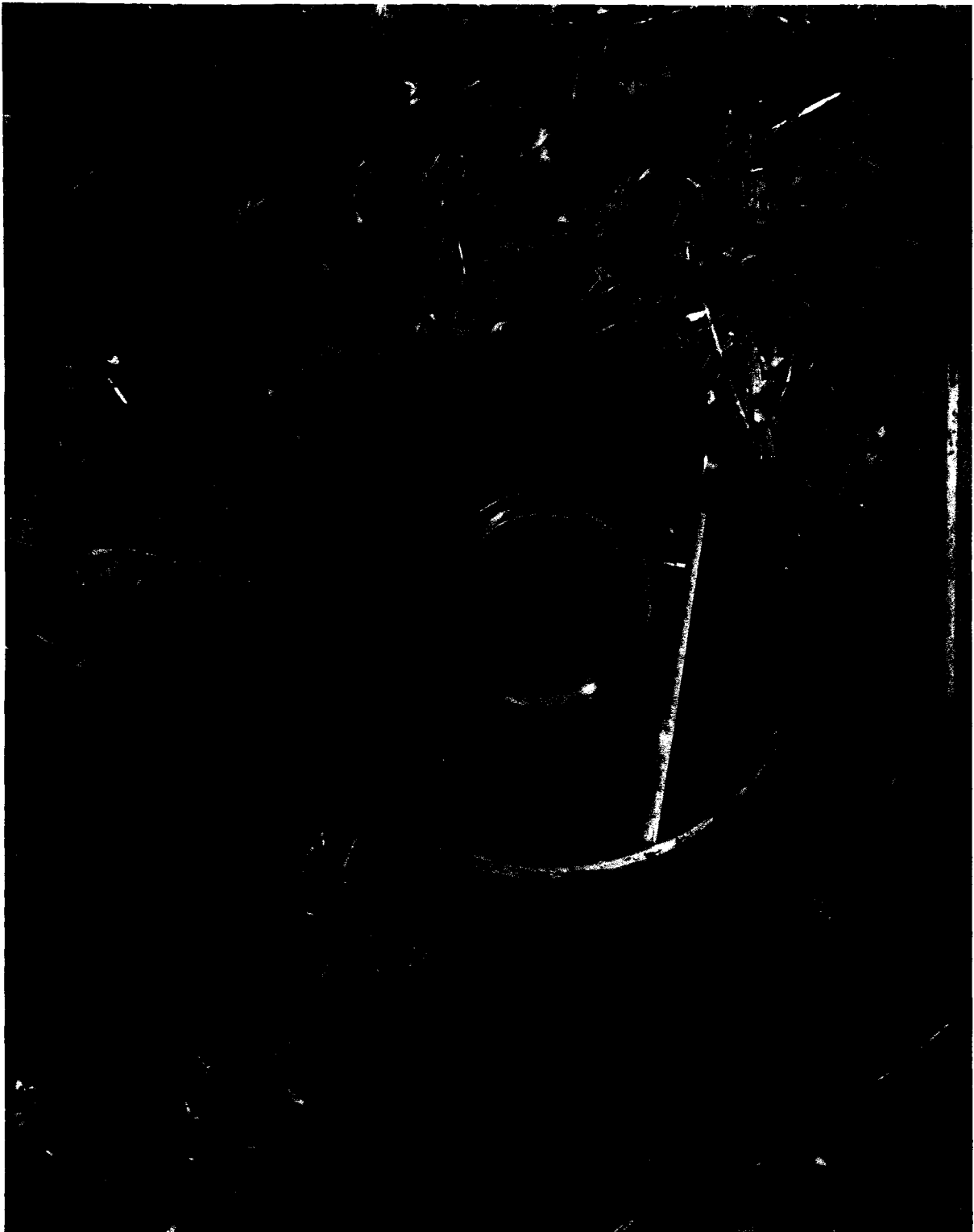
After the soil had been covered for a sufficient period of time to come to an equilibrium soil moisture near field capacity, it was uncovered and

allowed to dry for an hour or two. The drying period was necessary as moisture vapor within the covered cylinder condensed on the sides and walls and dripped back on the surface making the surface film too wet to work with until it had been allowed to dry somewhat. The surface inch of soil was removed from the area between the infiltration cylinder and the outer cylinder and sieved through an 8 mm. sieve. The soil passing through the 8 mm. sieve was air-dried and saved for laboratory analyses. A space was excavated under the run-off spout in which to place the milk bottles to catch the run-off (Figure 4). This space was made long enough to hold three pint milk bottles. However, there were never more than two bottles in the space at a time.

After the cover was removed from over the outer cylinder, and while the plot was drying, the rainfall simulator was set on a cylinder one foot high on an adjacent plot which was not to be studied. The hydraulic head, or water level in the water supply tank, was then adjusted for the rainfall rate of 4 inches per hour by regulating the height of the water in the head control tube. This was done by measuring the amount of water used by the rainfall-simulator in five minutes at a given head. The initial head setting for the first trial was one which had been used the previous day for a similar air temperature. Distilled water was used in the rainfall simulator to produce the rain, but tap or well water from the locality concerned was used to saturate the soil to field capacity.

If the water used in five minutes exceeded the intensity desired, the head was reduced by increasing the height of the water in the head control tube and the opposite adjustment was made if the intensity was too low. The head required to obtain the desired intensity of 4 inches per hour was

Figure 4. Infiltration cylinder installed, with milk bottle in pit under run-off spout, following air permeability measurement and prior to assembly of rainfall simulator. Outer retaining cylinder in place.



usually about 2 cm., but varied with temperature between the extremes of 1.5 and 3.5 cm., during the season in which the measurements were made. Air temperatures during this period varied between extremes of 88° F to 32° F, with most of the working temperatures being in the fifties or sixties. After the desired intensity and head level were obtained, another five minute rainfall run was made and the water delivery checked. If this was in agreement with the previous determination, the instrument was considered adjusted and ready for an infiltration determination.

An air permeability measurement was made when the soil moisture was at field capacity and before the infiltration measurement, in the following manner: The run-off trough (C) was thoroughly cleaned and rinsed. The run-off spout (M) was plugged with "Absorene", non-crumbly wallpaper cleaner, and the rubber O-ring fitted over the infiltration cylinder. The air permeameter was set over the infiltration cylinder in such a manner that the O-ring was forced down against the run-off trough and the O-ring shoulder (D) of the air permeameter. The run-off trough was then filled with water and the trough checked for leaks, while a float was allowed to move downward as during an air permeability measurement. If no leaks were noted, a minimum of three air permeability measurements were made and the air temperature taken in the shade. Air permeability was calculated in absolute units ( $\mu^2$ ) by the equation given by Grover (35), assuming 95 percent relative humidity. The procedure for calculating air permeability is given in Appendix II.

After making the air permeability measurements, the air permeameter and O-ring were removed and the run-off trough rinsed and cleaned out. The splash shield was then set on the run-off trough and the windshield fitted

to the splash shield. The water supply tank was placed on top of the wind-shield and the tripod and water reservoir mounted on the supply tank. An empty pint bottle was placed under the run-off spout. The quantity of water calculated to be necessary for the desired head was poured into the water supply tank, the stop-watch was started, and the stop-cock opened on the water supply reservoir. The rainfall simulator, assembled and in operation, is shown in Figure 5.

The time was noted at which run-off started and recorded on the milk bottle, which had one side etched for recording information. Milk bottles were changed at five minute intervals and stoppered tightly with a rubber stopper to prevent evaporation and contamination. The water level in the water reservoir was recorded at five minute intervals beginning at thirty seconds after rainfall was started. Air and water temperature were taken several times during each infiltration measurement, and the head in the water supply tank was measured each time a bottle was changed. If the water delivery during a five minute interval was extremely high or low, a correction was made by regulating the hydraulic head and changing the cut-off level in the water reservoir.

Rainfall and time were terminated when the water reservoir level indicated two inches had been delivered. Rainfall was stopped by lifting the water supply tank with reservoir off and setting the assembly on a stand placed on an adjacent empty plot. After the rainfall and time were stopped, bottles were changed, so that an empty bottle would be under the run-off spout to catch the material to be washed out. The windshield was removed from the splash shield, which was left standing in place (Figure 6). A laboratory wash bottle was used to direct a stream of water on the inside of the splash

Figure 5. Rainfall simulator assembled and in operation. Note air-bubbles rising in water reservoir and head control tube.



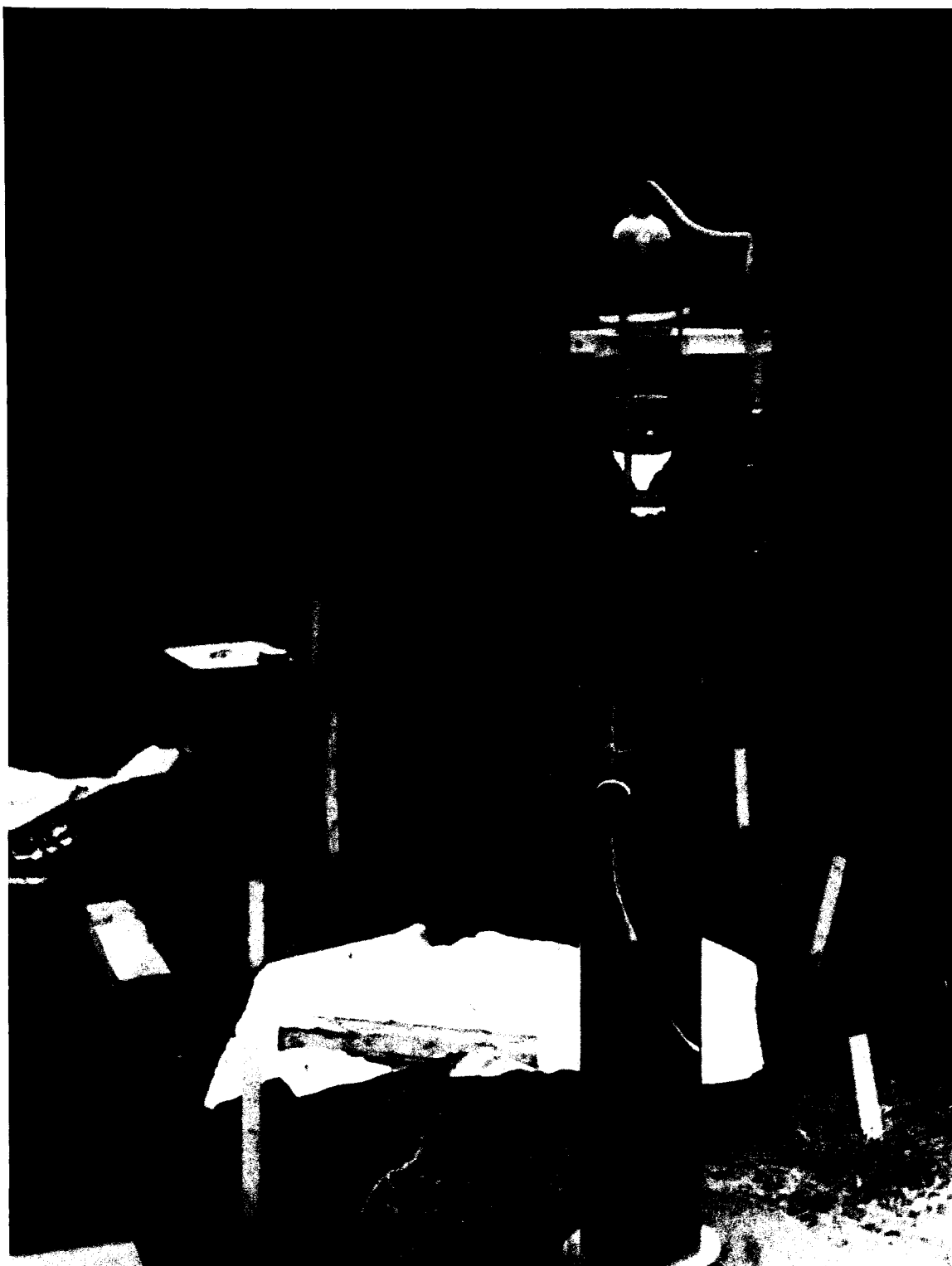


Figure 6. Infiltration cylinder with splash shield in place, immediately following termination of rainfall. Rainfall simulator and wind shield have been removed. Note water standing on soil surface and splash erosion on sides of splash shield and in run-off trough.



shield, which rinsed the adhered splash off and into the run-off trough. The splash shield was then removed (Figure 7) and the sediment remaining in the run-off trough washed into the milk bottle by use of the wash bottle (Figure 8).

A core sample was taken between the infiltration cylinder and the outer cylinder from a depth  $2 \frac{9}{16}$  inches to  $3 \frac{7}{16}$  inches below the soil surface. The core sample was taken in a small brass cylinder  $1 \frac{3}{4}$  inches in diameter and  $\frac{7}{8}$  inches high, which was inserted into a larger steel sampling cylinder and forced into the soil to the desired depth. Cores were trimmed roughly and sealed in a small moisture-can for transportation to the laboratory. For sandy and coarse silt soils a square of cheese cloth was placed over each end of the core to prevent crumbling in transit. The sampling tube and retention cylinder used to take core samples, were similar to the apparatus described in USDA Handbook No. 60 for collecting moisture retention samples (69).

#### Laboratory Procedures

##### Run-off, infiltration, and erosion

The outer surfaces of the pint milk bottles, containing the run-off samples collected in the field, were washed to remove any mud that may have dried on them. The stopper was removed, and the bottle and contents weighed on a torsion balance to 0.1 gram. One molar aluminum nitrate solution was added to the run-off, in the ratio of 1 cc.  $\text{Al}(\text{NO}_3)_3$  solution to 100 cc. run-off, to flocculate the suspended sediment. After adding the flocculent, the bottle was stoppered, shaken thoroughly, and allowed to stand for 24 hours. After standing 24 hours the samples were clear, and the supernatant

Figure 7. Infiltration cylinder, following rinsing and removal of splash shield. Note splash erosion in run-off trough. Water standing on surface in Figure 5 has now soaked in.









liquid was siphoned off. The flocculated soil was washed into 100 cc. beakers and evaporated to dryness at 105° C. The beakers containing the oven-dried, eroded soil, were placed in dessicators to cool and weighed on an analytical balance to 0.0001 gram.

Run-off water was determined as weight in grams and converted to volume. Infiltration was determined as the difference between the amount of water applied in a five minute interval and the run-off for the corresponding time interval. Run-off and infiltration data were used to calculate the inches per hour of run-off and infiltration and the total inches of run-off and infiltration.

The oven dry sediment weights were used to calculate the rate of erosion for each time period, in tons per acre per hour and the total erosion in tons per acre.

#### Moisture-retention determination

The cores collected in the field were stored in a constant temperature room at about 38° F. until all field work was finished, to reduce bacterial activity or any microbiological changes.

The moisture retention data were obtained by using the method described on page 110 of USDA Agricultural Handbook No. 60 (69). Each core sample was covered with a plastic lid, and placed on a porous ceramic disc. The plastic lids and ceramic discs were fastened to the brass cylinders by stretching rubber bands across the lids and attaching the bands to hooks at the opposite edges of the ceramic discs. Core samples were saturated from the bottom up, by slowly raising the water level to nearly the height of the cylinder. The samples were allowed to stand in the water 48 hours before any tension was applied. Moisture retention was determined at the following water

tensions: 0 cm., 10 cm., 30 cm., 60 cm., and 100 cm., 1/3 atmosphere, and 1 atmosphere. The 0 and 10 cm. water tension values were determined on a blotter pad tension plate. All higher values were determined in the pressure cooker apparatus. Samples were allowed to stand for 24 hours at the two lower tensions of 0 and 10 cm., and at the higher tensions until equilibrium was attained. The data obtained were used to calculate the percentage moisture by volume at the different tensions and were plotted as moisture-tension curves.

#### Aggregate<sup>1</sup> stability in water

The soil samples collected in the field and air-dried, were split into two equal portions. One half was used for aggregate water-stability analysis, and the other half for determining the dispersion ratio. Aggregate-stability was determined by a modification<sup>2</sup> of the aggregate-size distribution procedure in USDA Handbook No. 60 (69).

The half of each sample saved for aggregate analysis was passed, without forcing, through a 5 and 2 mm. sieve. The portion remaining on the 5 mm. and that passing through the 2 mm. sieve, were discarded. A 25 gram sample for analysis was taken from the portion retained on the 2 mm. sieve. The sample was then added to the top sieve of a nest of sieves, which was oscillated vertically under water for 30 minutes. The mechanism was adjusted so that the screen made contact with the water surface when the oscillation mechanism was at the top of the stroke. The sieve set consisted of a

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<sup>1</sup>The term aggregate as used herein is understood to include some primary particles as well as true aggregates.

<sup>2</sup>Mimeographed procedure prepared by the North Central States Soil Research Technical Committee NC-17, January 1955.

series of sieves with openings of 2, 1, 0.5, 0.25 and 0.10 mm. The portion of the sample retained on each sieve at the end of 30 minutes, was washed into evaporating dishes and oven dried at 105° C for 24 hours. The oven dried material was weighed to 0.01 gram and the percentage of the total weight of each fraction was computed on an oven dry basis. The per cent of soil remaining of the several screens is reported and also an average diameter (the mean-weight diameter) of the particles, the average being for all the screens.

#### Dispersion ratio

The dispersion ratio was determined for the 0.02 mm. size fraction by a modified pipette analysis, for both a dispersed and non-dispersed sample. The portion of the sample saved for pipette analysis was coarsely ground to pass a 2 mm. sieve. The procedure for the non-dispersed sample was as follows: A sample of air dry soil, equivalent to 10 grams of oven-dry soil, was weighed and placed in a quart milk bottle with sufficient distilled water to make a total volume of 900 cc. The bottle was tightly stoppered and shaken end-over-end by hand for 60 seconds. A stop watch was started at the end of shaking, and a pipette withdrawal made at 10 cm. depth at the required time interval for the 0.02 mm. size fraction to have settled below 10 cm. The pipetted sample was then quantitatively transferred to a 50 cc. weighed beaker and oven dried for 24 hours at 105° C. The oven dried sample was cooled in a dessicator, weighed on an analytical balance to 0.0001 gram, and the percentage of the total oven dry weight of the 0.02 mm. fraction calculated.

A similar procedure was followed for the dispersed analysis except that the 10 gram oven-dry sample was added to a high speed mixer cup.

Then 250 cc. of distilled water and 10 cc. of sodium hexametaphosphate solution<sup>1</sup> were added and the sample mixed by the mixer for 10 minutes. The sample was then quantitatively transferred to the milk bottle and the volume diluted with distilled water to 900 cc. The same procedure for both the dispersed and non-dispersed was followed from this step on.

The dispersion ratio (51) was calculated by dividing the total oven dry weight of 0.02 mm. and finer fraction from the non-dispersed analysis, by the total oven dry weight of the same size fraction in the dispersed sample and multiplying the quotient by 100.

$$\text{Dispersion ratio} = \frac{\text{gm. oven dry material} \leq 0.02 \text{ mm. non-dispersed}}{\text{gm. oven dry material} \leq 0.02 \text{ mm. dispersed}} \times 100$$

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<sup>1</sup>35.7 grams sodium metaphosphate and 7.94 grams sodium carbonate in one liter of solution.

## RESULTS

## Infiltration, Run-off, and Erosion

Preliminary investigations

Preliminary, exploratory investigations indicated that both the stage, or crop of the rotation, and initial soil moisture content affected erosion losses as obtained by this method. These results are in general agreement with those obtained by others for the effect of the cropping system upon average annual soil loss (38) and the effect of initial soil moisture upon infiltration (56). Results of the preliminary investigations are given in Tables 2, 3, and 4 and Figures 9, 10, 11, and 12. These data show that the erosion rate reached a peak well in advance of the period of maximum run-off. This peak always occurred during the first few minutes after run-off started, regardless of whether the surface soil was initially moist or dry. However, a longer period of rainfall was required before run-off occurred for soils which were initially very dry. The author, while employed by the United States Geological Survey, has frequently observed a similar situation in streams in the Missouri Basin during and after periods of high rainfall, in which the sediment concentration in the stream reached a peak and decreased before the maximum water discharge was attained. Similar results are shown in sediment and water discharge curves for floods on several streams in the United States in an article by Love (46).

On Clarion silt loam, which was in first year corn, nearly 1 inch of artificial rainfall was required before run-off and erosion started. On this same soil, after 4 inches of rain were applied, water had penetrated to a depth of 14 inches below the soil surface, and a maximum of 2 inches

Table 2. Run-off, infiltration, and erosion rates obtained with the rainfall simulator on the Clarion silt loam in first year corn of a C-C-O-M rotation, with the soil surface initially very dry.<sup>a</sup>

	Time interval in minutes											Total
	0-R <sup>b</sup>	R-15	15-20	20-25	25-30 <sup>c</sup>	30-35	35-40	40-45	45-50	50-55 <sup>d</sup>	55-60	
Run-off (in/hr)	0	1.01	1.02	1.07	1.12	0.92	0.98	1.06	1.16	1.31	1.37	0.86 in.
Infiltration (in/hr)	4.23 <sup>e</sup>	3.22	3.21	3.16	3.11	3.31	3.25	3.17	3.07	2.92	2.86	3.37 in.
Erosion (acre ton/hr)	0	2.25	1.03	0.91	0.76	0.47	0.53	0.46	0.58	0.59	0.50	13.80 tons

<sup>a</sup>Infiltration cylinder placed on the center of the ridge between corn plants.

<sup>b</sup>R = time at which run-off noted. Run-off started at 13.56 min.

<sup>c</sup>Refilled volumetric flask during run. Flask empty at 27 min.

<sup>d</sup>Flask emptied during this run but not refilled.

<sup>e</sup>Same as rainfall intensity.

Table 3. Run-off, infiltration, and erosion rates obtained with the rainfall simulator from the center of ridges between corn plants at two locations on Clarion silt loam in second year corn of a C-C-O-M rotation.

	Time interval in minutes							
	0-R <sup>a</sup>	R-5	5-10	10-15	15-20	20-25	25-F <sup>b</sup>	Total
Location 1. Soil surface initially very dry.								
Run-off (in/hr)	0	0.36 <sup>c</sup>	1.91	2.93	2.98	3.02	2.13 <sup>d</sup>	1.12 in.
Infiltration (in/hr)	4.59 <sup>e</sup>	4.23	2.67	1.66	1.62	1.57	1.91	1.24 in.
Erosion (tons/acre/hr)	0	0.40	3.86	1.71	1.57	1.43	0.56	8.53 tons
Location 1. Allowed to stand about 4 hours after above rain and run again.								
Run-off (in/hr)	0 <sup>f</sup>	1.91 <sup>g</sup>	2.90	3.79 <sup>h</sup>				0.72 in.
Infiltration (in/hr)	4.59 <sup>e</sup>	2.68	1.69	0.80				0.53 in.
Erosion (tons/acre/hr)	0	1.50	0.87	0.91				2.38 tons
Location 2. Soil surface dry.								
Run-off (in/hr)	0 <sup>f</sup>	0.02 <sup>i</sup>	0.92	1.48	1.70	1.40	0.75 <sup>j</sup>	0.55 in.
Infiltration (in/hr)	4.01 <sup>e</sup>	3.98	3.09	2.53	2.31	2.60	1.79	1.67 in.
Erosion (tons/acre/hr)	0	0.13	2.27	1.41	1.23	0.64	0.28	9.45 tons

<sup>a</sup>R = time run-off noted.

<sup>f</sup>Time started at time of run-off.

<sup>b</sup>F = time rainfall terminated.

<sup>g</sup>Run-off started at 1.25 min.

<sup>c</sup>Run-off started at 4.15 min.

<sup>h</sup>Rainfall terminated at 15.0 min.

<sup>d</sup>Rainfall terminated at 31.5 min.

<sup>i</sup>Run-off started at 3.75 min.

<sup>e</sup>Same as rainfall intensity.

<sup>j</sup>Rainfall terminated at 31.92 min.

Table 4. Run-off, infiltration, and erosion rates obtained on Clarion silt loam in the fall of the oat<sup>a</sup> phase of a C-C-O-M rotation, at two locations with different initial surface moisture.

	Time interval in minutes						Total
	0-R <sup>b</sup>	R-5	5-10	10-15	15-20	20-25	25-F <sup>c</sup>
Location 1. Soil surface dry.							
Run-off (in/hr)	0 <sup>g</sup>	0.32 <sup>d</sup>	1.16	1.73	2.10	2.44 <sup>e</sup>	0.64 in.
Infiltration (in/hr)	4.13 <sup>f</sup>	3.81	2.97	2.40	2.03	1.69	1.37 in.
Erosion (tons/acre/hr)	0	0.87	0.86	1.19	1.40	0.72	8.17 tons
Location 2. Soil pre-soaked and allowed to drain to field capacity.							
Run-off (in/hr)	0 <sup>g</sup>	1.30 <sup>h</sup>	2.78	3.58	3.52	3.48 <sup>i</sup>	2.49 <sup>j</sup> 1.64 in.
Infiltration (in/hr)	4.13 <sup>f</sup>	2.83	1.35	0.55	0.61	0.56	0 0.79 in.
Erosion (tons/acre/hr)	0	1.59	1.18	0.76	0.83	0.85	0.44 5.34 tons

<sup>a</sup>About two weeks after oats were harvested.

<sup>b</sup>R = time run-off noted.

<sup>c</sup>F = time rainfall terminated.

<sup>d</sup>Run-off started at 4.5 min.

<sup>e</sup>Rainfall terminated at 25 min.

<sup>f</sup>Same as rainfall intensity.

<sup>g</sup>Time started when run-off noted.

<sup>h</sup>Run-off started at 4.30 min.

<sup>i</sup>Flask empty at 23.27 min. but tank allowed to empty.

<sup>j</sup>Rainfall terminated at 35.0 min.



Figure 9. Run-off, infiltration and erosion rates obtained on Clarion silt loam at location 1 in second year corn of a C-C-O-M rotation. 1. Surface initially dry. 2. Same plot 4 hours later, surface wet. Data taken from Table 3.

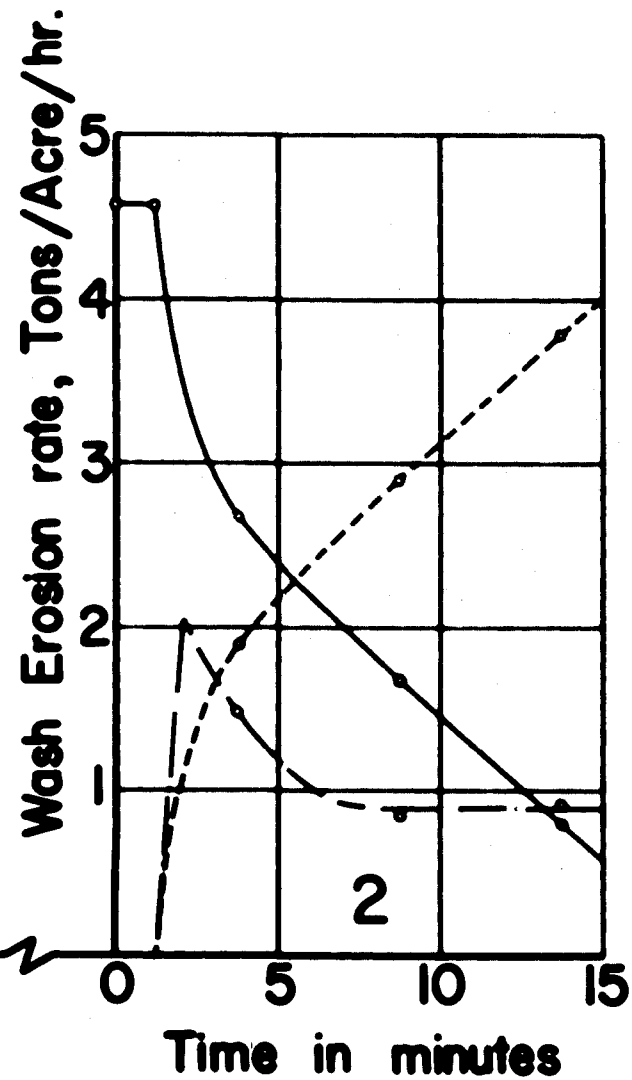
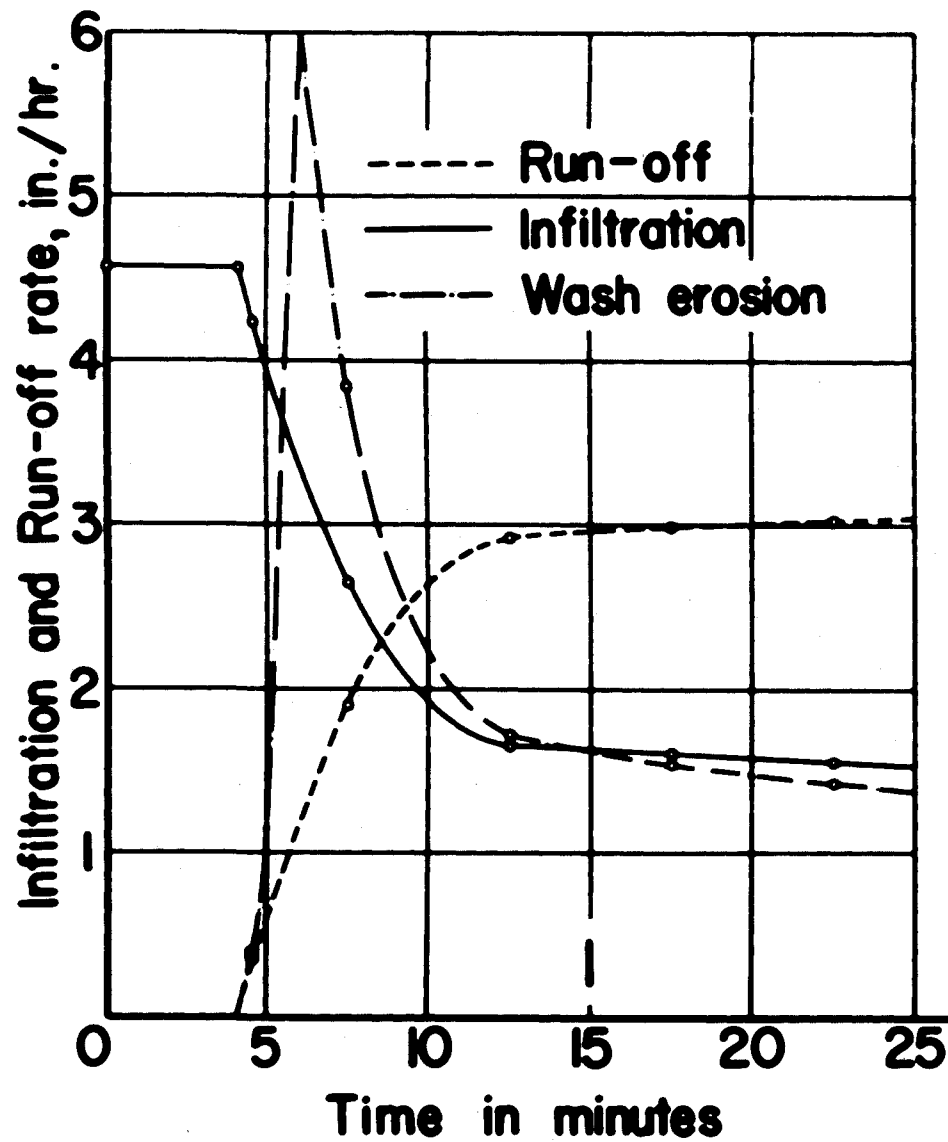


Figure 10. The effect of different crop phases of a C-C-O-M rotation upon total infiltration and run-off on a Clarion silt loam. 1, 3, 4, 5, initially dry; 2, same location as 1 but 4 hours after rain; 6, soil initially at field capacity moisture level. All data corrected to the basis of 2.01 inches of rain.

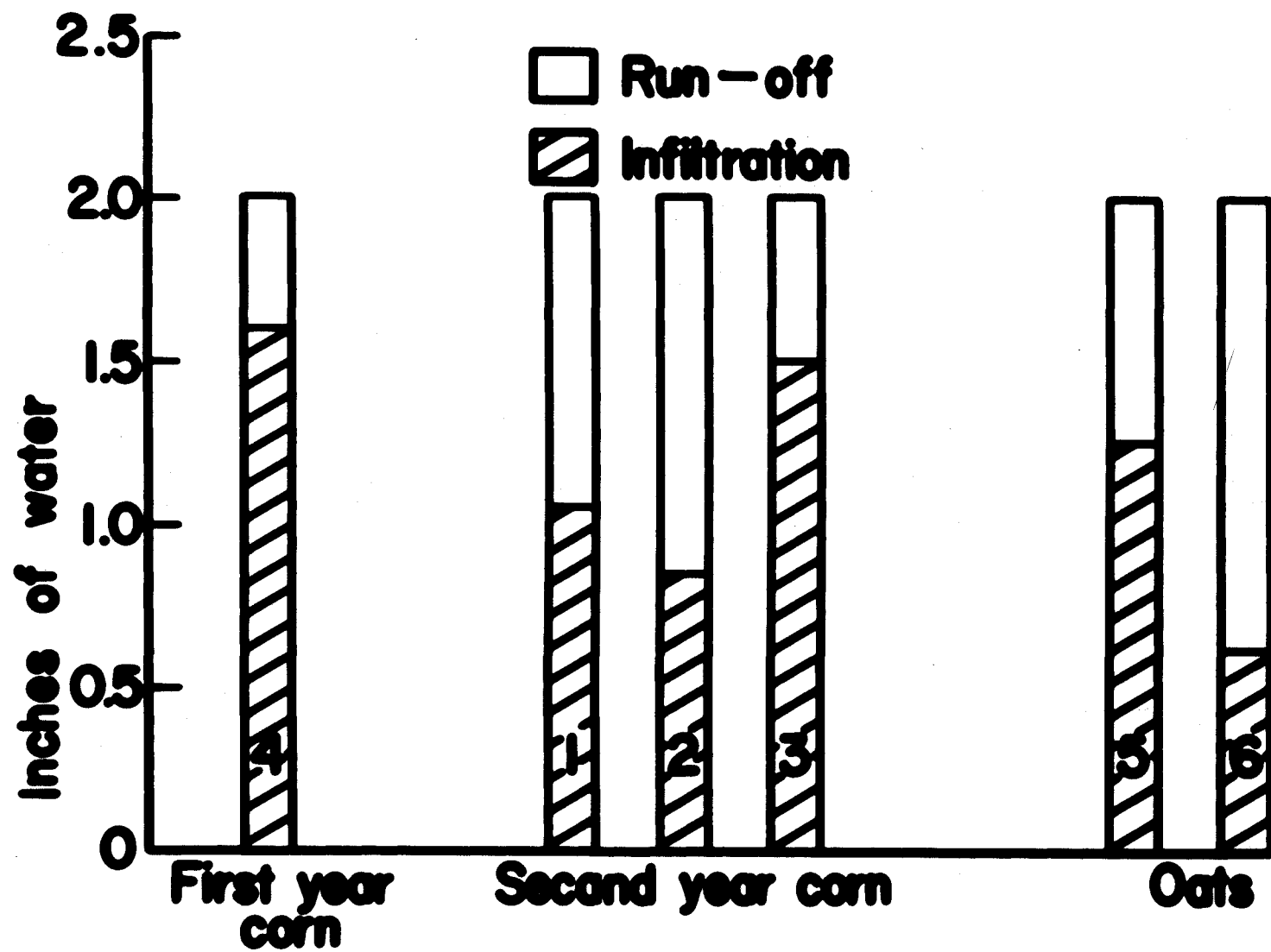


Figure 11. The effect of different phases of a C-C-O-M rotation, and initial soil moisture condition upon total wash erosion and splash erosion on a Clarion silt loam. All data corrected to the basis of 2.01 inches of rain. 1, 3, 4, 5, initially dry; 2, same location as 1 but 4 hours after rain; 6, soil initially at field capacity moisture level.

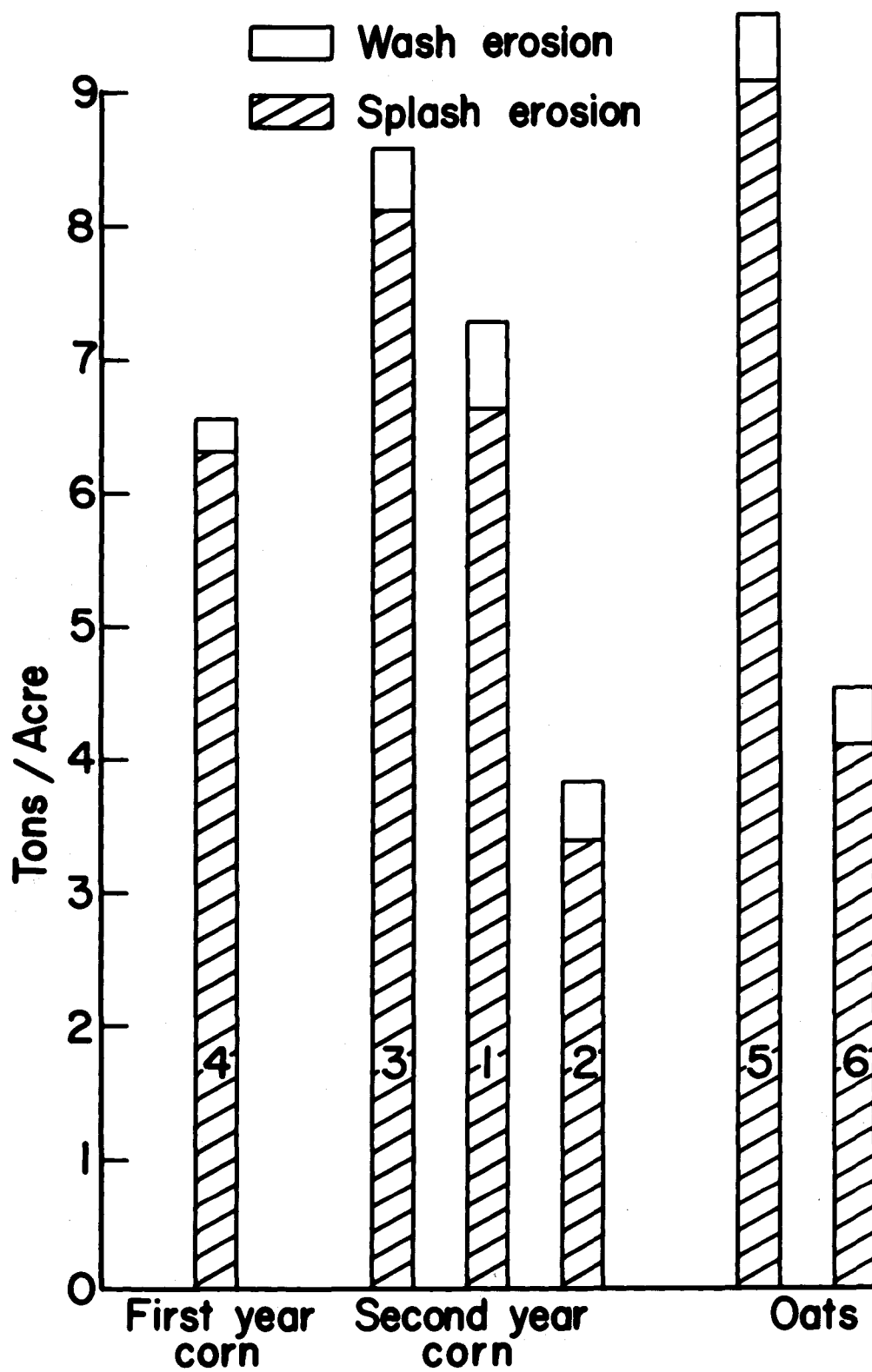
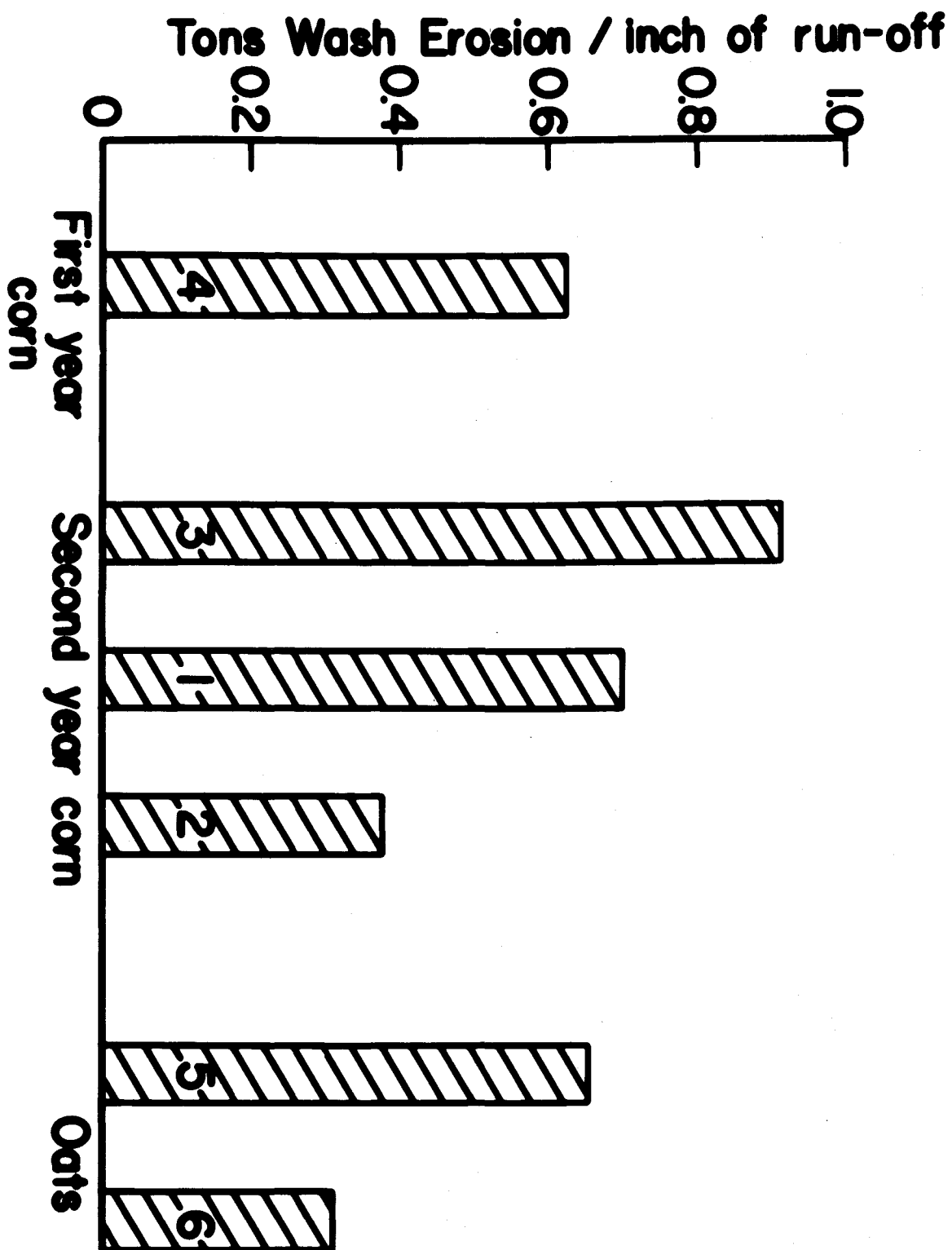


Figure 12. The effect of different phases of a C-C-O-M rotation and initial soil moisture on wash erosion per acre inch of run-off on a Clarion silt loam. 1 and 3, initially dry; 2, same location at 1 but 4 hours after rain; 4, initially dry; 5, initially dry; 6, soil initially at field capacity.





laterally from the cylinder. These preliminary data, calculated on a basis of 2.01 inches of rain, gave indications that infiltration under the various cropping practices of the rotation was in the order: First year corn > second year corn > oats (Figure 10). Splash erosion appeared to be about equal for oats and second year corn and was the least for first year corn (Figure 11). Splash erosion was approximately twice as great when the rain fell on soil which was initially dry (Figure 11), regardless of the cropping practice. Wash erosion was also greater when rain fell upon soil which was initially dry. While the preliminary data were too limited to allow definite conclusions, they did indicate that there was some effect of cropping practice and initial soil moisture.

#### Results of the field investigations

Data on the run-off, infiltration, and wash erosion rates for the soils studied are given in Tables 5, 6, and 7 and shown in Figures 13, 14, and 15. The run-off and infiltration rate curves were both smooth, with infiltration decreasing as run-off increased. A nearly steady rate of run-off and infiltration was reached within the 15 to 20 minute time interval after rainfall started for all soils studied except the Thurman. At the completion of the application of 2.01 inches of rainfall, the Thurman soils still had a high rate of infiltration, averaging 3.07 in. per hr. for the last 4 minutes of rainfall. The run-off rate for the Thurman was increasing rapidly at the end of the rainfall. During the last time interval the rate increased about 0.5 inches over the preceding time interval. For all the soils studied, run-off started between the first and second minute after the rainfall started. All the soils studied, except the Thurman, had very similar run-off and infiltration curves. As a group, the infiltration

Table 5. Average run-off rates and total run-off on eight Iowa soils from 2.01 inches of rain applied with the rainfall simulator. Determinations were made in the fall of the oat phase of a C-C-O-M rotation<sup>a</sup>, with the soil initially at field capacity and surface cultivated.

Soil	Average R <sup>b</sup> (min.)	Average run-off intensity per time interval(in./hr.)							Average F (min.)	Average total run-off (in.)	Average rainfall intensity (in./hr.)
		0-R	R-5 <sup>c</sup>	5-10	10-15	15-20	20-25	25-F <sup>d</sup>			
Webster <sup>e</sup>	1.91	0	1.43	2.48 (0.19) <sup>f</sup>	3.09 (0.22)	3.25 (0.19)	3.40 (0.12)	3.46 (0.13)	30.7	1.42 (0.05)	3.93 (0.08)
Shelby <sup>g</sup>	1.8	0	1.45	3.21 (0.12)	3.59 (0.14)	3.70 (0.13)	3.65 (0.09)	3.77 (0.24)	31.4	1.64 (0.29)	3.87 (0.10)
Clarion <sup>h</sup>	2.16	0	1.51	2.63 (0.15)	2.90 (0.16)	3.21 (0.20)	3.32 (0.13)	3.42 (0.12)	29.8	1.36 (0.07)	4.01 (0.05)
Grundy <sup>e</sup>	1.43	0	2.39	3.89 (0.11)	4.03 (0.11)	4.01 (0.11)	4.05 (0.09)	4.12 (0.11)	29.2	1.76 (0.02)	4.13 (0.09)
Monona <sup>e</sup>	1.34	0	2.67	3.82 (0.14)	3.90 (0.12)	3.99 (0.10)	3.99 (0.09)	3.96 (0.13)	29.4	1.76 (0.10)	4.11 (0.08)
Ida <sup>h</sup>	2.07	0	1.67	2.84 (0.14)	3.41 (0.08)	3.54 (0.08)	3.58 (0.10)	3.61 (0.08)	30.2	1.50 (0.03)	4.00 (0.05)
Thurman <sup>e</sup>	1.98	0	0.10	0.03 (0.01)	0.12 (0.09)	0.34 (0.22)	0.62 (0.26)	1.08 (0.29)	29.1	0.18 (0.07)	4.15 (0.07)
Marshall <sup>e</sup>	1.46	0	2.35	3.64 (0.10)	3.82 (0.07)	3.83 (0.08)	3.90 (0.08)	4.21 (0.13)	30.1	1.75 (0.03)	4.02 (0.07)

<sup>a</sup>Four year rotation of corn, corn, oat, meadow.

<sup>b</sup>R = Time at which run-off started.

<sup>c</sup>Time in minutes

<sup>d</sup>F = Finishing time to deliver two inches of rain.

<sup>e</sup>Average of ten replicates.

<sup>f</sup>Data in parentheses is the standard error(Sx) for the run-off rate for the time interval.

<sup>g</sup>Average of eight replicates.

<sup>h</sup>Average of nine replicates.

Table 6. Average infiltration rates for eight Iowa soils in the fall of the oat phase of a C-C-O-M rotation, from 2.01 inches of rain applied with the rainfall simulator, with the soil initially at field capacity, and surface cultivated.

Soil	Average infiltration intensity per time interval (in./hr.)							Average total infiltration in.
	0-R <sup>a</sup>	R-5 <sup>b</sup>	5-10	10-15	15-20	20-25	25-F <sup>c</sup>	
Webster <sup>d</sup>	3.93 (0.08) <sup>e</sup>	2.50	1.44 (0.19)	0.84 (0.18)	0.68 (0.17)	0.52 (0.10)	0.46 (0.10)	0.59 (0.06)
Shelby <sup>f</sup>	3.87 (0.10)	2.42	0.66 (0.12)	0.28 (0.04)	0.17 (0.06)	0.22 (0.05)	0.22 (0.08)	0.38 (0.03)
Clarion <sup>g</sup>	4.01 (0.05)	2.51	1.37 (0.15)	1.10 (0.14)	0.80 (0.12)	0.69 (0.16)	0.61 (0.12)	0.62 (0.05)
Grundy <sup>d</sup>	4.13 (0.09)	1.74	0.25 (0.04)	0.11 (0.03)	0.14 (0.04)	0.11 (0.03)	0.09 (0.03)	0.26 (0.01)
Monona <sup>d</sup>	4.11 (0.08)	1.44	0.29 (0.06)	0.21 (0.05)	0.12 (0.03)	0.13 (0.03)	0.16 (0.07)	0.25 (0.02)
Ida <sup>g</sup>	4.00 (0.05)	2.33	1.17 (0.13)	0.60 (0.06)	0.47 (0.06)	0.43 (0.07)	0.40 (0.04)	0.51 (0.03)
Thurman <sup>d</sup>	4.15 (0.07)	4.05	4.12 (0.08)	4.04 (0.14)	3.82 (0.25)	3.54 (0.27)	3.07 (0.30)	1.84 (0.07)
Marshall <sup>d</sup>	4.02 (0.07)	1.68	0.38 (0.09)	0.20 (0.05)	0.19 (0.04)	0.14 (0.03)	0.06 (0.03)	0.28 (0.02)

<sup>a</sup>R = time at which run-off first started.  
Values for R given in Table 5.

<sup>b</sup>Time in minutes

<sup>c</sup>F = finishing time to deliver 2 inches of rain. Values for F given in Table 5.

<sup>d</sup>Average of ten replicates.

<sup>e</sup>Data in parenthesis is the standard error ( $S_{\bar{x}}$ )  
for the infiltration rate for the time interval.

<sup>f</sup>Average of eight replicates.

<sup>g</sup>Average of nine replicates.

Table 7. Average wash erosion rates and total erosion for eight Iowa soils in the fall of the oat phase of a C-C-O-M rotation, from 2.01 inches of rain applied with the rainfall simulator, with the soil initially at field capacity, and surface cultivated.

Soil	Run-off erosion intensity per time interval (acre tons/hr.)							Average total erosion (ton/acre)
	0-R <sup>a</sup>	R-5 <sup>b</sup>	5-10	10-15	15-20	20-25	25-F <sup>c</sup>	
Webster <sup>d</sup>	0	1.079	1.961 (0.274) <sup>e</sup>	1.996 (0.239)	1.714 (0.262)	1.695 (0.244)	1.696 (0.363)	7.322 (0.803)
Shelby <sup>f</sup>	0	0.991	1.417 (0.142)	1.102 (0.104)	1.042 (0.140)	0.962 (0.128)	0.842 (0.097)	6.482 (0.435)
Clarion <sup>g</sup>	0	1.088	1.861 (0.153)	1.560 (0.113)	1.637 (0.137)	1.325 (0.121)	1.001 (0.107)	5.139 (0.553)
Grundy <sup>d</sup>	0	2.056	2.537 (0.224)	2.084 (0.203)	1.767 (0.197)	1.576 (0.181)	1.385 (0.157)	7.062 (0.394)
Monona <sup>d</sup>	0	2.585	2.526 (0.197)	1.906 (0.174)	1.682 (0.154)	1.560 (0.176)	1.487 (0.186)	6.577 (0.324)
Ida <sup>g</sup>	0	1.389	1.462 (0.215)	1.311 (0.175)	1.110 (0.140)	0.993 (0.134)	0.909 (0.127)	4.343 (0.316)
Thurman <sup>d</sup>	0	0.029	0.015 (0.004)	0.017 (0.009)	0.028 (0.014)	0.073 (0.023)	0.217 (0.058)	9.499 (1.992)
Marshall <sup>d</sup>	0	2.474	3.417 (0.157)	2.843 (0.208)	2.381 (0.171)	2.034 (0.131)	2.092 (0.192)	6.986 (0.459)

<sup>a</sup>R = time at which run-off started. Values for R given in Table 5.

<sup>b</sup>Time in minutes.

<sup>c</sup>F = finishing time to deliver 2 inches of rain. Values for F given in Table 5.

<sup>d</sup>Average of ten replicates.

<sup>e</sup>Standard error ( $S\bar{x}$ ) within parenthesis for the erosion rate for the time interval.

<sup>f</sup>Average of eight replicates.

<sup>g</sup>Average of nine replicates.

Figure 13. Average run-off rates for eight Iowa soils, in the fall of the oat phase of a C-C-O-M rotation, from 2.01 inches of rain applied with the rainfall simulator, with the soil initially at field capacity, and surface cultivated.

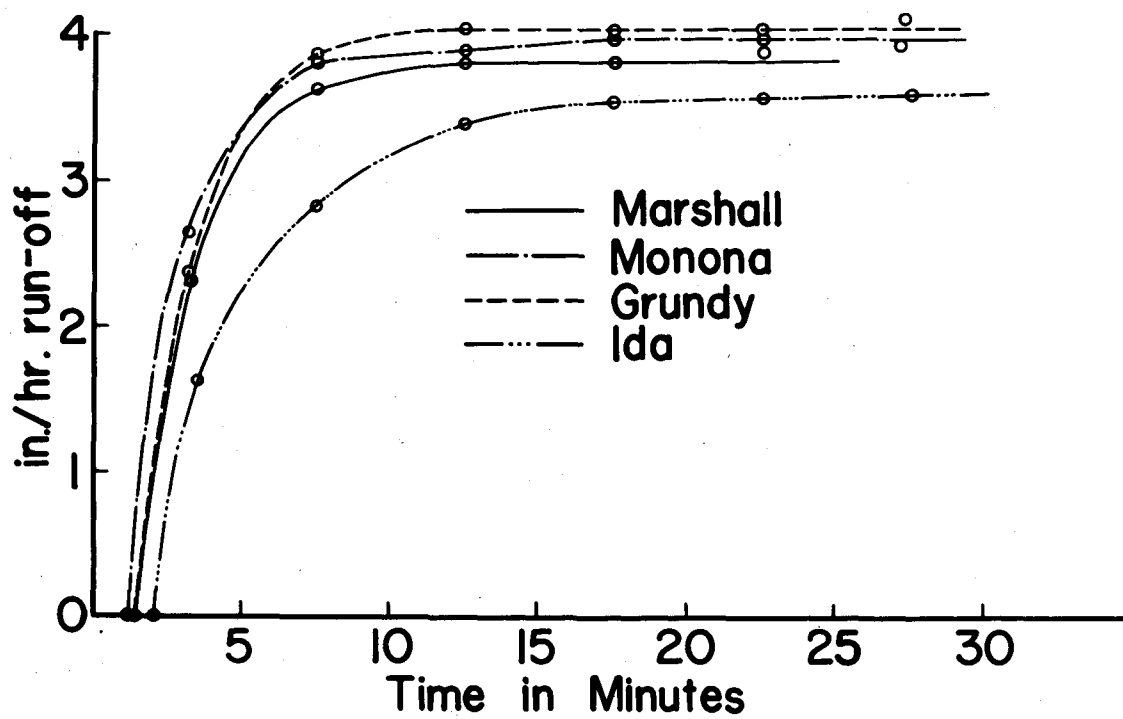
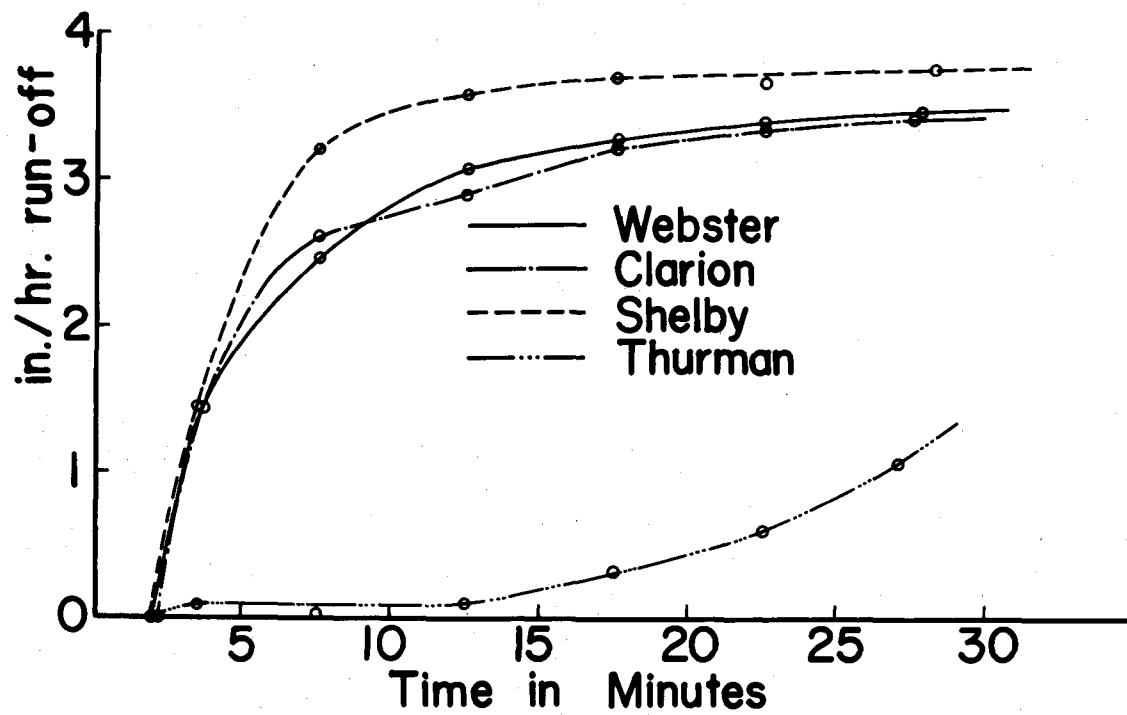


Figure 14. Average infiltration rates for eight Iowa soils in the fall of the oat phase of a C-C-O-M rotation, from 2.01 inches of rain applied with the rainfall simulator, with the soil initially at field capacity, and surface cultivated.

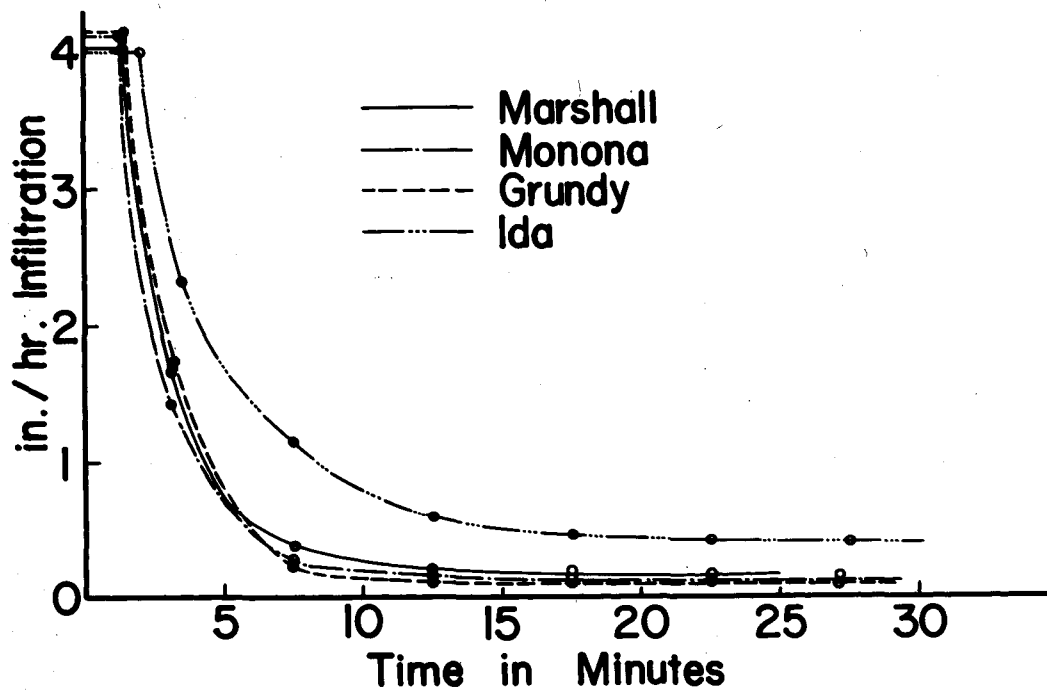
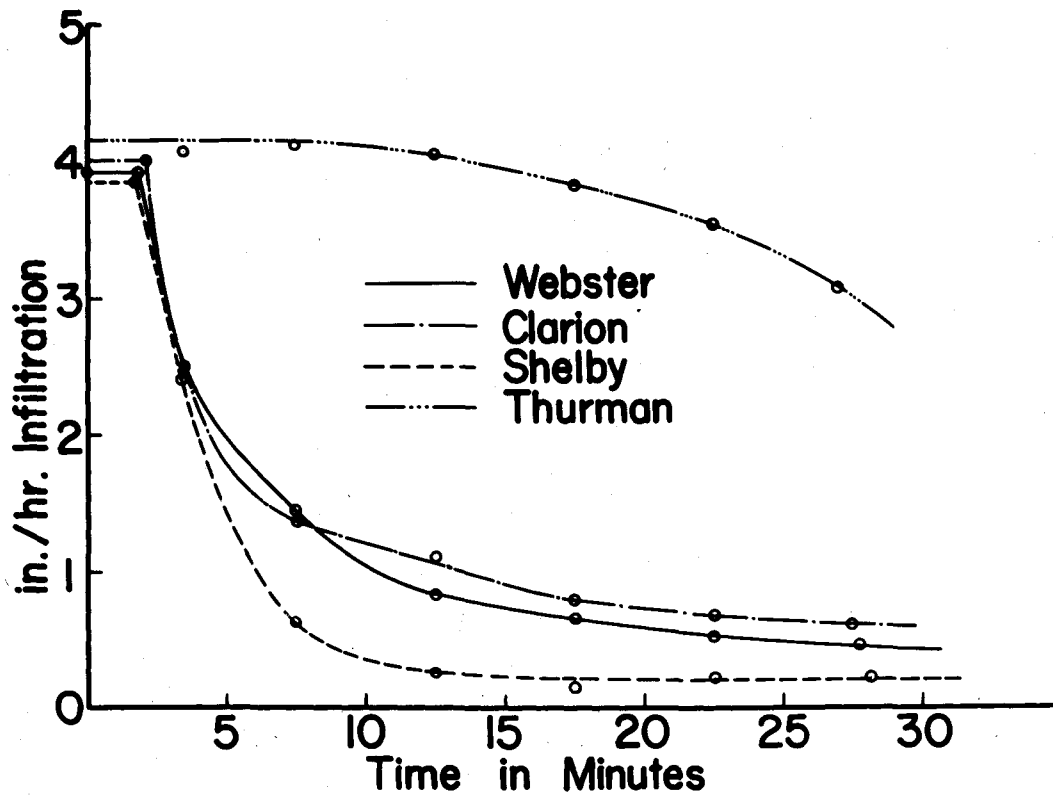
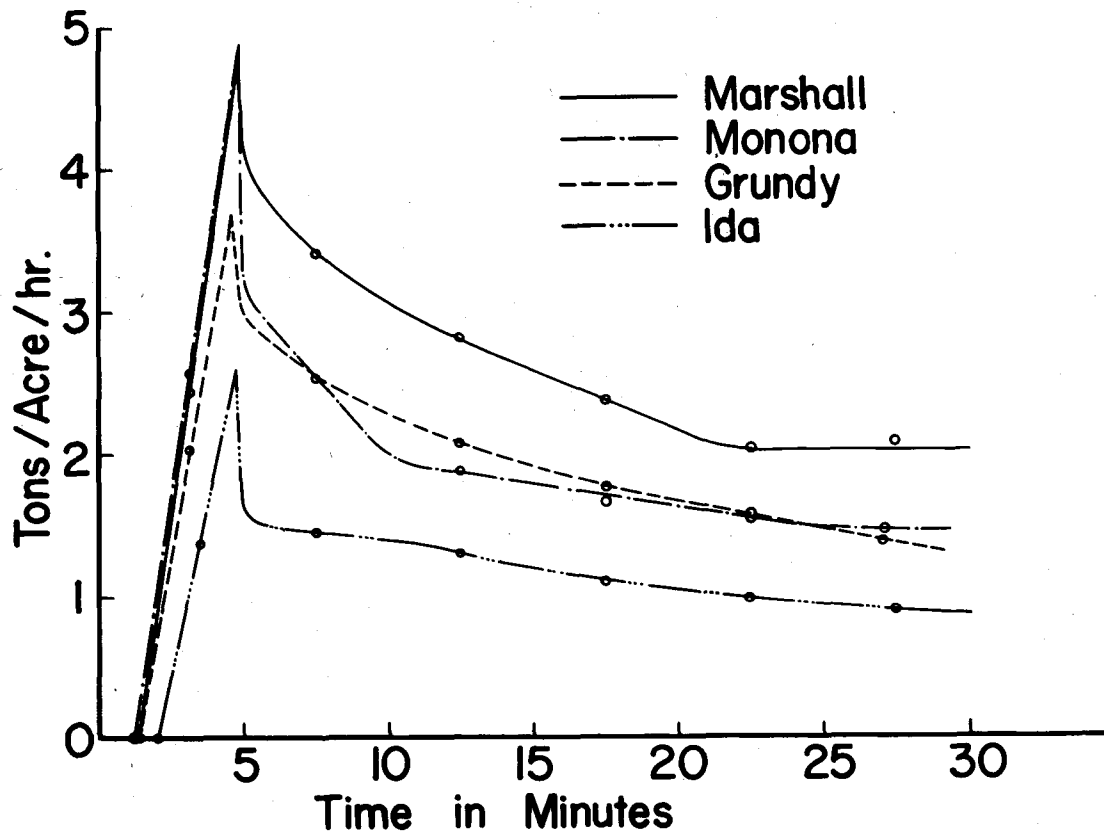
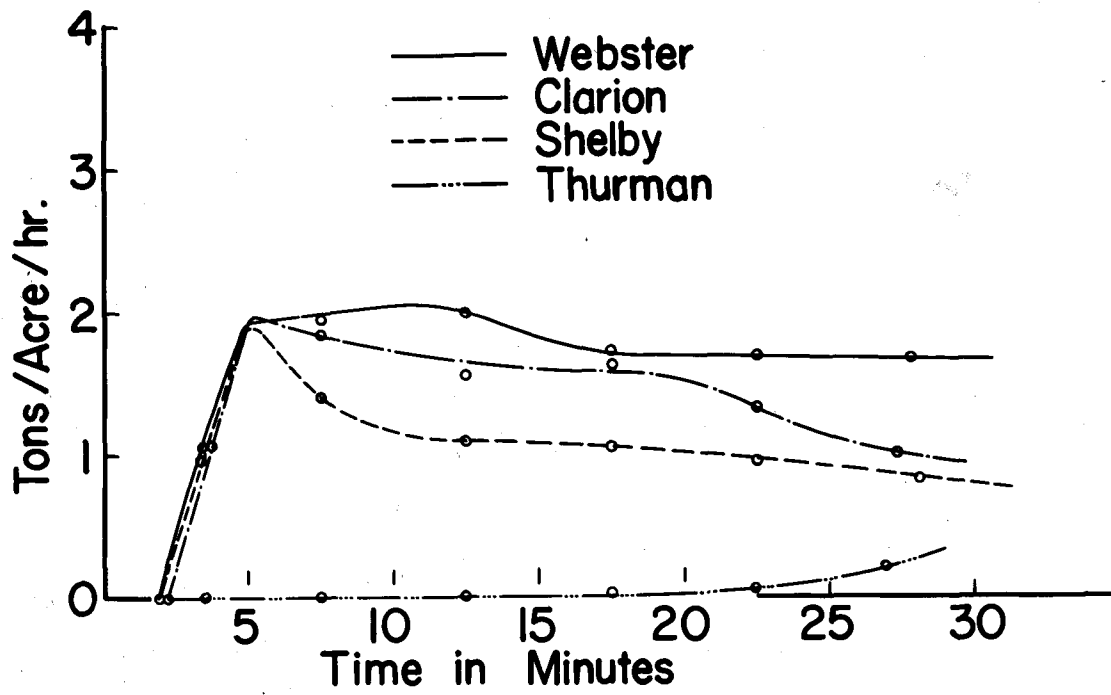




Figure 15. Average wash erosion rates for eight Iowa soils in the fall of the oat phase of a C-C-O-M rotation from 2.01 inches of rain applied with the rainfall simulator, with the soil initially at field capacity, and surface cultivated.



rates in the 20 to 25 minute time interval varied from 0.1 to 0.7 in. per hr. and the run-off from 3.2 to 4.1 in. per hr. This larger group could be roughly divided into two groups. The first group consisted of the Grundy, Marshall, Monons, and Shelby soils, and had an infiltration rate in the 20 to 25 minute time interval varying from 0.1 to 0.2 in. per hr. and a run-off rate ranging from 3.8 to 4.2 in. per hr. The second group consisted of the Ida, Clarion, and Webster soils. This group had a minimum infiltration rate varying from 0.4 to 0.7 in. per hr. and a maximum run-off rate ranging from 3.2 to 3.6 in. per hr.

The 20 to 25 minute time interval was selected as the interval to determine the minimum infiltration rate and the maximum run-off rate because of variations during the last time interval which occasionally caused the run-off rate to appear to be higher than the actual rainfall rate. This discrepancy was probably due to the method of finishing the determination. At the time when 2.01 inches of rain had been delivered it was necessary to perform the following operations: (1) stop the time, (2) turn off the water delivery tube and remove rainfall simulator-water tank assembly, and (3) change bottles under run-off spout. When two people were operating the instrument it was possible to perform these operations in about 10 seconds. When there was only one person, it frequently took over 30 seconds to perform all the operations and since changing the milk bottles was usually last, there was run-off over a larger time interval than was used in the calculations. Rainfall could probably be terminated quicker by use of a removable interceptor slide below the rainfall applicators. With the slide in place all rainfall would be diverted outside of the plot area. The bottles could be changed more rapidly by use of a tipping trough mechanism below the run-off spout, similar to that used by Pearse and Bertleson (65) with the square-

foot infiltrometer. The discrepancies noted for the last time interval could be reduced or eliminated if the above modifications were made.

The erosion-rate curves in Figure 15 show a high and sharp peak during the first five minutes. The exact timing and height of the peak are not known, but since the plotted values are averages for the time interval it is necessary that the curve go above the points as well as below. The curves were drawn through the plotted average values in all cases, which may have caused some distortion of the curve in the first five minutes. It is possible that the peak erosion rate occurred during the first minute of run-off and steadily decreased throughout the remainder of the first time interval to join with the curve in the next five minute time interval.

Soil which was eroded or removed by the run-off water during the five minute time intervals was designated as wash erosion. The displacement or movement of soil, from the exposed soil surface and its deposition in the run-off trough throughout the entire period of rainfall, was designated as splash erosion. Splash erosion was determined only for the entire period of rainfall as it was not possible to determine short time rates by the method employed. Erosion occurring during run-off was caused as much or more by the dispersive and mixing action of the falling raindrops as it was by the run-off action of the excess water. Since the plots were level, the only action of running water was that which flowed over the edge of the plot into the run-off trough and out the run-off spout.

Of the soils studied, the Thurman had the lowest wash erosion rate throughout the entire period of rainfall, and even at the end of the rainfall the wash erosion rate was still less than 0.1 ton per acre per hour. The wash erosion rate from the Thurman was still increasing at the end of

the rainfall, but at a very slow rate. Of the other seven soils, the Marshall, Monona, and Webster appeared to have reached a stabilized rate of erosion. The remaining four appeared to be decreasing at the end of the rainfall. However, to be consistent with the run-off and infiltration rates, the 20 to 25 min. time interval was used as the time of an essentially stable wash erosion rate for comparing soils. Based on the 20 to 25 minute time interval, the eight soils could be divided into three wash erosion groups. The lowest group consisted of the Thurman soil with an erosion rate of less than 0.1 ton per acre per hour. The middle group, with a minimum erosion rate of from 0.96 to 1.30 tons per acre per hr., consisted of the Shelby, Ida, and Clarion soils. The highest rate group varied from 1.56 to 2.03 tons per acre per hr. and consisted of the Monona, Grundy, Webster and Marshall soils. (Table 7, Figure 15)

The total inches of water which ran-off or infiltrated during the 2.01 inches of rainfall are given in Tables 5 and 6, and Figure 16. The Thurman soil occupied a distinctive position, having about 0.05 inch of run-off and 1.96 inches of infiltration. The remaining soils could be considered as falling into one large group, which varied from 1.35 to 1.76 inches of run-off and from 0.25 to 0.66 inches of infiltration, or into two groups within these extremes, with the dividing line at 1.5 inches of run-off and 0.51 inches of infiltration. If the soils other than Thurman were to be divided into two groups, the group with the lower run-off would consist of the Clarion, Webster and Ida soils with the remaining soils in the higher run-off group.

The soils are arranged in the order of decreasing erodibility in Table 8, and Figure 17. The soils were divided into different categories or

Table 8. Comparison of wash erosion, splash erosion, and total erosion for eight Iowa soils and their division into groups<sup>a</sup> which differ statistically. Based on data obtained from 2.01 inches of artificial rain applied with the rainfall simulator.

Wash Erosion		Splash Erosion		Total Erosion	
Soil	Total <sup>b</sup>	Soil	Total	Soil	Total
Marshall	1.20 (0.06) <sup>c</sup>	Thurman	9.47 (1.99)	Thurman	9.50 (1.99)
		----- d -----		----- d -----	
Monona	0.90 (0.08)	Webster	6.50 (0.84)	Webster	7.32 (0.80)
Grundy	0.88 (0.09)	Grundy	6.18 (0.36)	Grundy	7.06 (0.39)
Webster	0.83 (0.11)	Shelby	5.97 (0.41)	Marshall	6.99 (0.19)
Clarion <sup>e</sup>	0.67 (0.04)	Marshall	5.79 (0.49)	Monona	6.58 (0.32)
Ida	0.55 (0.07)	Monona	5.68 (0.36)	Shelby	6.48 (0.44)
Shelby	0.52 (0.05)	Clarion	4.47 (0.53)	Clarion	5.14 (0.55)
Thurman	0.03 (0.01)	Ida	3.80 (0.26)	Ida	4.34 (0.32)

<sup>a</sup>Solid lines separate groups in which the means are statistically significant.

<sup>b</sup>Total expressed in tons per acre.

<sup>c</sup>Standard error in parenthesis ( $\bar{Sx}$ ).

<sup>d</sup>Broken line separates groups of soils based on other physical factors or measurements.

<sup>e</sup>A border-line soil. Fits statistically in either group.

Figure 16. Total infiltration and run-off from 2.01 inches of artificial rain applied with the rainfall simulator to eight Iowa soils.

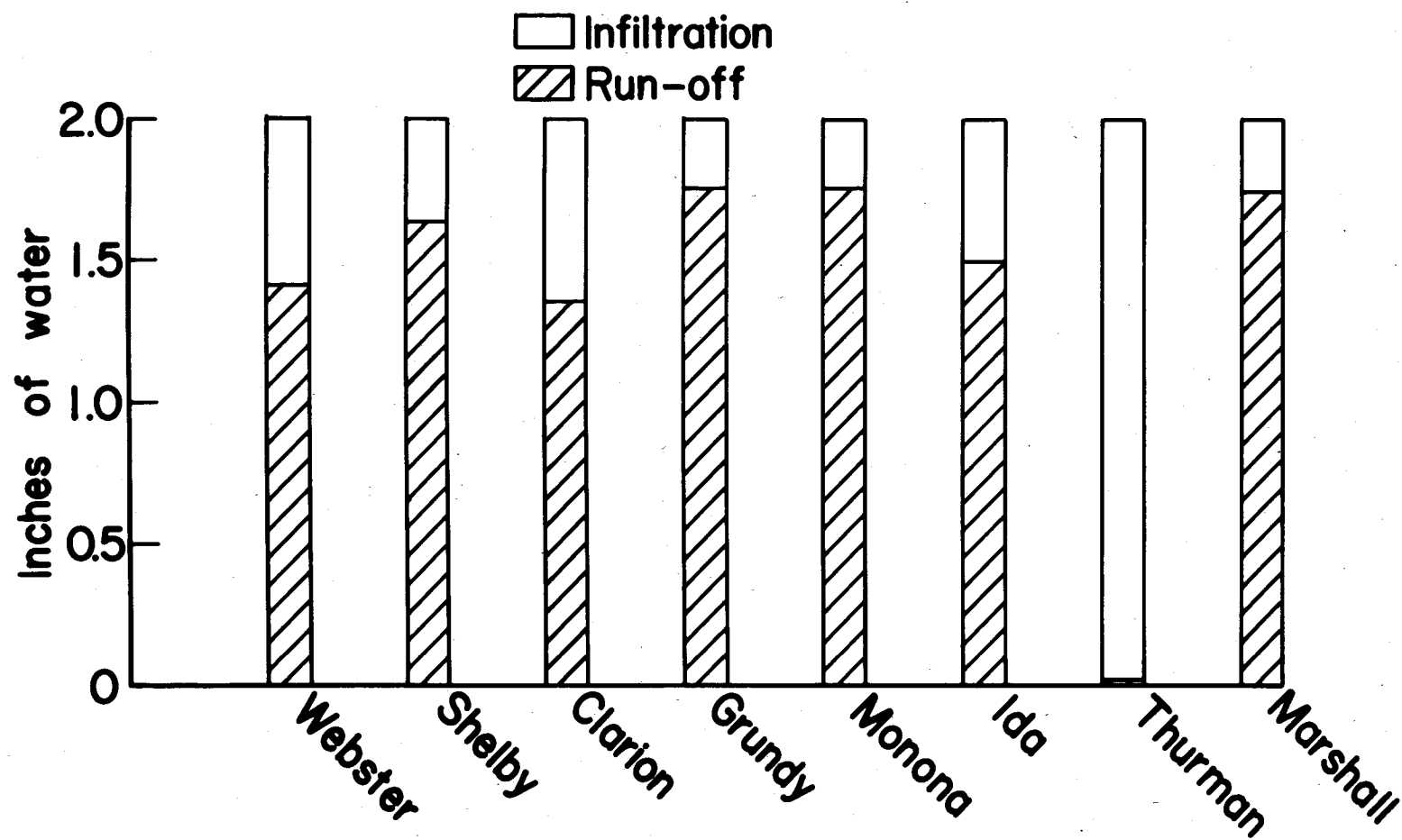
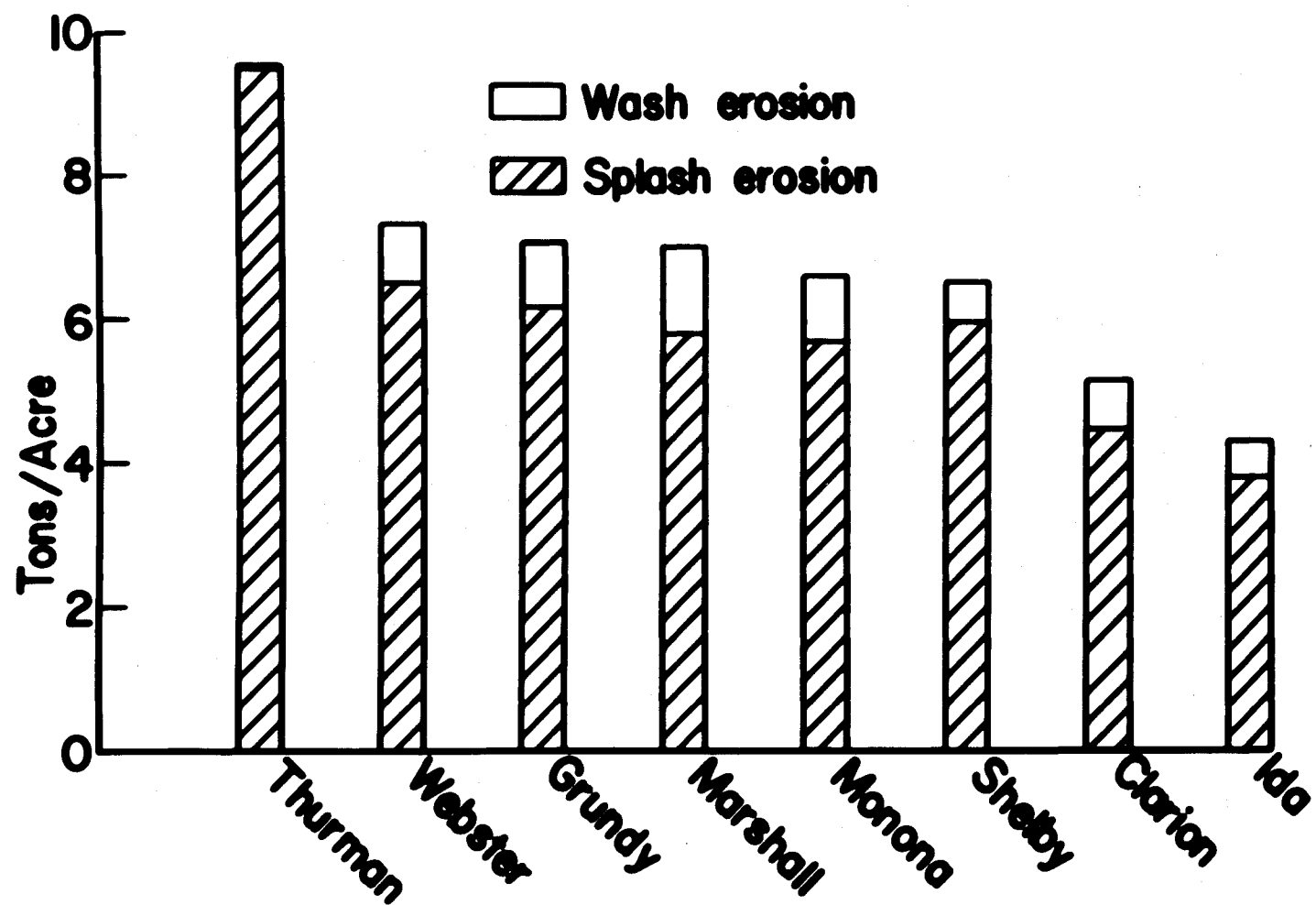




Figure 17. Total erosion, subdivided into wash and splash erosion, for eight Iowa soils caused by 2.01 inches of rain from rainfall simulator.



classes for wash, splash and total erosion by the use of the t-test to study the difference of the means. The groups are set up on the basis of a statistical difference of the means at the five per cent level of significance. The soils were divided into four statistically different groups for wash erosion and two different groups for splash erosion as shown by the lines in Table 8. The Marshall soil, with 1.20 tons per acre, had the most wash erosion for 2.01 inches of rain and the Thurman with 0.03 tons per acre had the least. The Thurman soil, with 9.47 tons per acre, had the highest splash erosion and the Ida, with 3.80 tons per acre, had the least. Statistically, the soils could only be divided into two groups for splash erosion and total erosion, consisting of the Ida and Clarion as the least erodible, and the remaining soils falling in a broader group of higher erosion. No significant differences were obtained between the means of the Thurman and soils with higher total erosion than the Clarion. There was a statistical difference between the Thurman and Clarion soils. The Thurman was placed in a separate group in both splash erosion and total erosion even though there was not a statistical difference between the results obtained for the Thurman and the remainder of the more erodible soils. This separate grouping was established, based on textural differences and also because the total erosion for the Thurman consisted of 99.7 per cent splash erosion. Splash erosion varied from 82.8 per cent to 92.1 per cent for the remaining soils.

When the total wash erosion was calculated on the basis of tons per inch of run-off (Table 9), the soils remained in the same general order of erodibility, except for the Webster, but the absolute differences were reduced considerably. Such a rating or arrangement makes it possible to compare the resistance of the soils to an equal quantity of run-off.

Table 9. Comparison of wash erosion per inch of run-off for eight Iowa soils.

Soil	Wash erosion per in. run-off (tons/acre)	Soil	Wash erosion per in. run-off (tons/acre)
Marshall	0.686	Clarion	0.496
Webster	0.585	Ida	0.367
Monona	0.511	Shelby	0.313
Grundy	0.503	Thurman	0.150

However, since the ability of a soil to absorb and transmit water through its profile is an important factor affecting erosion, infiltration should be considered when evaluating the natural susceptibility of different soils to erosion.

#### Air Permeability

Air permeability data are given in Table 10 and Figure 18. Air permeability measurements at 1 and 2 hour intervals were not made on the Shelby and Grundy soils, as it appeared that the soil would freeze before the studies could be completed. Air permeability values were taken for the other six soils at 1 and 2 hour time intervals after rainfall was terminated, as well as at field capacity, before rainfall. The values, in general, reflected the textural differences of the soils. The coarser textured soils were more permeable to air at both time intervals. Based on texture, the Thurman sand would be expected to be the most permeable, but the Ida silt loam had recovered 67 per cent of its air permeability at field capacity at the end of 2 hours as compared to 38 per cent for the Thurman

Table 10. Air permeability in  $\mu^2$  for six Iowa soils at field capacity before rainfall, and at intervals after 2.01 inches of artificial rainfall was terminated.

Soil	Air permeability in $\mu^2$			
	Before <sup>a</sup> rain	60 min. after rain	120 min. after rain	240 min. after rain
Webster	3.44 (0.94) <sup>b</sup>	0.90 (0.38)	1.31 (0.49)	----
Shelby	6.25 (1.07)	----	----	----
Clarion	7.51 (1.26)	1.19 (0.53)	1.82 (0.81)	----
Grundy	5.43 (1.09)	----	----	----
Monona	3.60 (0.49)	0	0.38 (0.32)	1.76 (0.78)
Ida	6.76 (0.85)	3.62 (0.72)	4.55 (0.74)	----
Thurman	7.50 (0.52)	2.42 (0.38)	2.86 (0.35)	----
Marshall	5.00 (1.54)	0.61 (0.27)	1.15 (0.44)	2.20 (1.01)

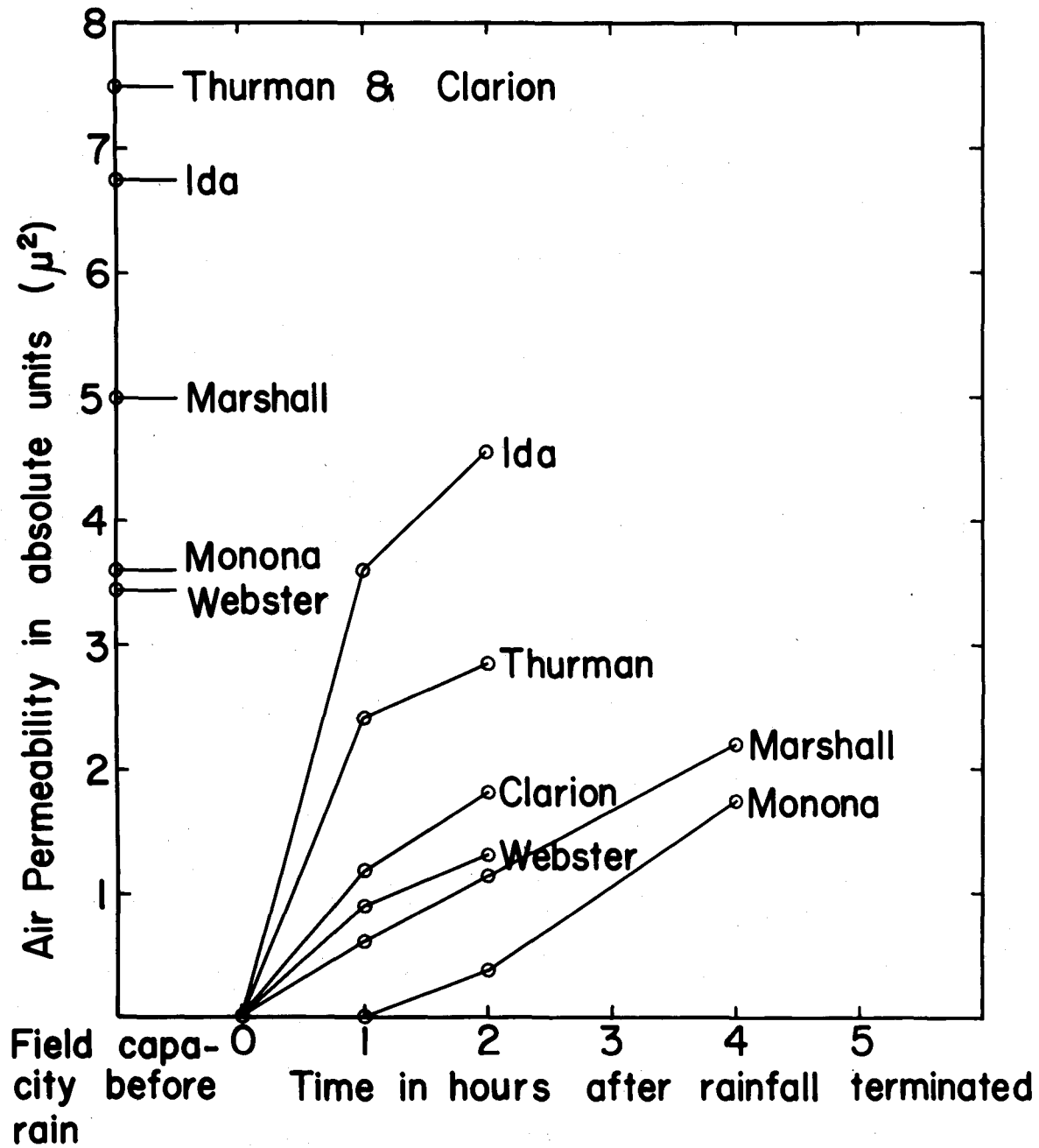
<sup>a</sup>Soil at field capacity.

<sup>b</sup>Values in parentheses are standard errors.

at the same time.

Several measurements were made at the end of 4 hours on the Marshall and Monona soils. The air permeability for Marshall had almost doubled and for Monona it had more than doubled at 4 hours over the values obtained at the end of 2 hours. However, the air permeability rate increased less from 60 to 120 minutes than during the 0 to 60 minutes time interval for all soils except the Monona, which did not become permeable until 60 minutes after rainfall had been terminated. A few air permeability measurements were made on some soils after longer periods of time. The results indicated

Figure 18. Air permeability in  $\mu^2$  for six Iowa soils at field capacity before rainfall, and at several time intervals after a 2 inch artificial rainfall was terminated.



that at the end of 24 hours the Ida soil had almost the same air permeability as at field capacity. In 24 hours the Clarion soil recovered about 75 per cent of its air permeability at field capacity.

#### Moisture-Tension Data and Aeration Pore Space

The moisture tension data are given in Tables 11 and 12 and the moisture retention curves in Figure 19. From the moisture retention curves, it can be

Table 11. Percentage of pores drained over two ranges of water column tension for the eight Iowa soils upon which infiltration measurements were made with the rainfall simulator.

Soil	0-60 cm. Tension		0-100 cm. Tension	
	Percentage of pores drained <sup>a</sup>	Standard error $S_{\bar{x}}$	Percentage of pores drained	Standard error $S_{\bar{x}}$
Monona	1.67	(0.58)	3.73	(0.73)
Marshall	2.90	(0.68)	4.89	(0.73)
Grundy	3.09	(0.65)	5.10	(0.71)
Ida	3.32	(0.84)	6.46	(0.96)
Clarion	3.52	(0.49)	6.19	(0.56)
Shelby	5.86	(0.98)	8.77	(1.04)
Webster	6.48	(0.94)	8.90	(0.99)
Thurman	22.41	(0.62)	25.89	(0.55)

<sup>a</sup>Per cent of total soil volume drained by a given tension.

seen that six of the soils varied from 43 per cent to 49 per cent moisture at 0 cm. of tension, and from 37 per cent to 44 per cent moisture at 100 cm. of tension. The Thurman and Clarion soils were very close to equal in moisture retention at 0 cm., but differed widely at 100 cm. of tension, having 9.5 per cent and 29.5 per cent moisture, respectively. At one atmosphere of tension, the soils appeared to fall in three separate groups. The Thurman,

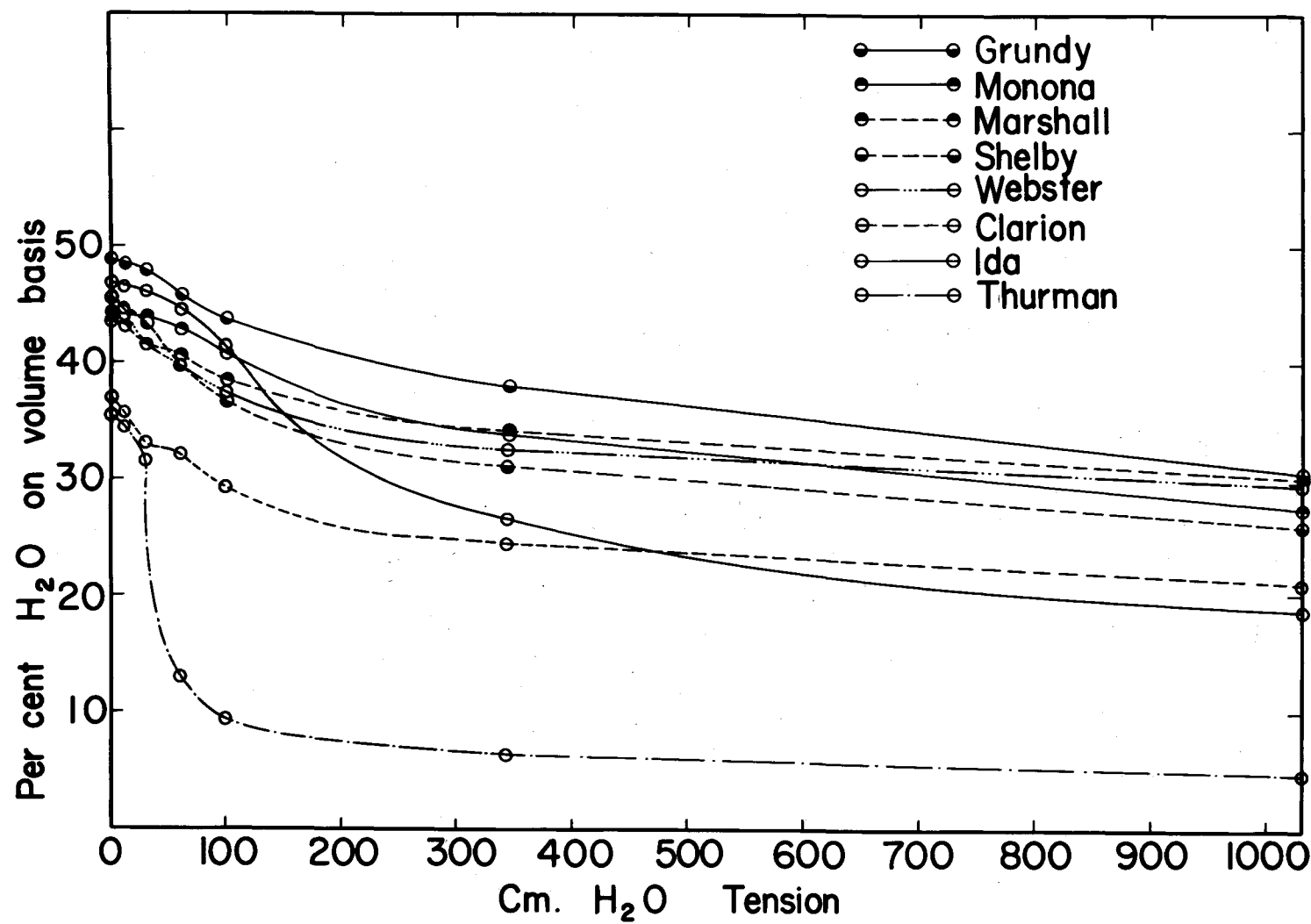


Table 12. Per cent water retained by different heights of water column tension for eight Iowa soils.

Column of water tension (cm.)	Per cent <sup>a</sup> water retained							
	Ida	Thurman	Monona	Grundy	Shelby	Marshall	Clarion	Webster
0	46.93	35.48	44.24	48.90	45.61	43.52	37.09	45.63
10	46.50	34.58	43.97	48.48	44.86	43.05	35.74	44.74
30	46.18	31.69	43.90	48.05	43.32	41.34	33.10	41.44
60	44.39	13.07	42.81	45.81	39.74	40.63	32.14	39.76
100	41.68	9.59	40.94	43.80	36.83	38.63	29.46	37.49
344	26.94	6.57	33.93	38.07	31.14	34.08	24.59	32.80
1033	18.69	4.83	27.42	30.54	26.00	30.11	21.03	29.47

<sup>a</sup>Per cent water on a volume basis.

Figure 19. Moisture retention curves from 0 cm. to 1 atmosphere of tension for the eight Iowa soils upon which infiltration measurements were made with the rainfall simulator.



having 4.8 per cent moisture, was the lowest group; the intermediate group consisted of the Clarion and Ida, having from 18.7 per cent to 21.0 per cent moisture; and the highest group consisted of the remaining soils, with the moisture content varying from 26.0 per cent to 30.5 per cent. Only the lower tension values would be expected to be related to infiltration and erosion in this study, as all soils were pre-soaked to be at field capacity at the time of rain. Therefore, on the basis of moisture tension data in the lower tensions, one might expect two or three levels of infiltration capacity which would influence the amount of erosion. The Thurman might be expected to be in a distinctive, separate position of high infiltration because of the high per cent moisture difference in the 0 to 100 cm. tension group. Based on similar reasoning, the Clarion and Ida could be expected to occupy an intermediate group and the remaining soils to be quite similar.

#### Aggregate Stability Results

Aggregate stability for the 2 to 5 mm. size fraction was determined for all soils except the Thurman. Results of the aggregate stability analyses are given in Table 13. The Ida had the highest percentage of aggregates<sup>1</sup> retained on the 2 mm. sieve and the Webster the lowest. However, the remaining size fractions indicated the Ida had a rather low aggregate stability, as it had the highest percentage of aggregates less than 0.10 mm. in size. Three soils, the Shelby, Grundy, and Clarion, had very similar aggregate stability, but the remaining soils did not appear

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<sup>1</sup>See footnote one on page 62.

Table 13. Percentage size distribution of aggregates after wet sieving dry soil that was originally between 5 and 2 mm. in diameter.

Soils	Percentage of sample within each size range						Mean weight diameter (mm.)
	5-2 <sup>a</sup>	2-1	1.0-0.5	0.5-0.25	0.25-0.10	<0.10	
Webster	3.8 (0.4) <sup>b</sup>	7.6 (0.5)	15.1 (0.7)	27.8 (0.6)	26.4 (0.8)	19.3	0.495
Shelby	12.0 (0.9)	10.8	12.2	22.0	22.8	20.2	0.783
Clarion	10.6 (1.1)	9.4	10.2	21.9	26.7	21.2	0.724
Grundy	13.4 (1.5)	10.9	12.1	18.8	18.1	26.8	0.820
Monona	5.9 (0.9)	7.3	7.3	12.6	22.1	44.8	0.463
Ida	17.0 (1.3)	8.7 (0.7)	3.7 (0.2)	5.3 (0.3)	8.8 (0.4)	56.5	0.821
Marshall	6.4 (0.5)	5.6	7.0	18.4	22.2	40.5	0.485

<sup>a</sup>Dimensions in millimeters.

<sup>b</sup>Standard error ( $S_x^2$ ) in parenthesis.

to fall into any particular aggregate stability group. If the stability of the larger aggregates is an indication of resistance to erosion, the Ida would be considered one of the least erodible; the Shelby, Grundy, Clarion of intermediate erodibility, and the remaining soils as the more erodible.

Dispersion Ratio and Size Fraction  $\leq 0.02$  mm.

Dispersion ratio data are given in Table 14. Middleton (51) suggested that soils with a dispersion ratio less than 15 could be classed as non-erodible. On this basis, the Grundy, Monona, Ida, Thurman, and Marshall soils would be expected to be erodible. If the magnitude of the dispersion

Table 14. Dispersion ratio and percentage size fraction  $\leq 0.02$  mm. of the surface inch for the eight Iowa soils used in the infiltration-erosion study.

Soils	Average dispersion ratio	Median dispersion ratio	Average percentage size fraction $\leq 0.02$ mm.	Median percentage size fraction $\leq 0.02$ mm.
Webster <sup>a</sup>	7.37 (0.36)	7.29	53.0 (0.2)	53.5
Shelby <sup>b</sup>	10.27 (0.16)	10.20	44.3 (0.3)	44.4
Clarion <sup>c</sup>	14.13 (0.67)	14.22	32.0 (0.2)	32.2
Grundy <sup>b</sup>	15.32 (0.27)	15.27	65.5 (0.1)	65.6
Monona <sup>b</sup>	18.42 (0.57)	18.24	49.8 (0.2)	49.6
Ida <sup>b</sup>	30.02 (0.99)	29.27	35.1 (0.2)	35.3
Thurman <sup>b</sup>	18.78 (1.25)	19.05	6.0 (0.1)	5.9
Marshall <sup>a</sup>	16.58 (0.41)	16.66	57.4 (0.3)	57.8

<sup>a</sup>Average or median of 12 replicates

<sup>b</sup>Average or median of 10 replicates

<sup>c</sup>Average or median of 11 replicates

ratio were definite indication of the degree of susceptibility to erosion, the Ida soil with a dispersion ratio of 30, would be expected to be the most erodible and the other four erodible soils would possess about the same degree of susceptibility to erosion. Actually, from the data obtained in this study (Table 8), the Ida was one of the least erodible soils but the Monona, Marshall, and Grundy were in an intermediate to more erodible group. The Thurman had a very low wash erodibility but was highly susceptible to splash erosion.

Dispersion analyses showed that the soils varied in silt and clay content from 5.9 per cent for the Thurman to 65.6 per cent for the Grundy, with the remaining soils varying from 30 to 60 per cent. These values indicate that all the soils were sandier than their soil-type name would imply. However, since these samples were all from the surface inch, it is possible that rains since the last cultivation had sorted the surface layer causing it to be coarser than the remainder of the plow layer.

#### Correlations

A number of correlation coefficients were calculated and the results are given in Table 15. Correlations<sup>1</sup> of the minimum infiltration rate vs. air permeability at field capacity and vs. air permeability at 60 minutes after rainfall, were statistically significant at the 5 per cent level. Correlations were highly significant for the minimum infiltration rate vs. 60 cm. water tension (for all soils and the mean value for each soil), 100 cm. water tension,  $1/3$  atmosphere water tension, and total pore space

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<sup>1</sup>Correlations are positive unless stated otherwise.

Table 15. The relation of field measurements to various laboratory determinations and to other field measurements as indicated by correlation coefficients and regression equations.

Physical measurements correlated <sup>a</sup>	Degrees of freedom	Correl. coeff.	Regression equation $\hat{y} = a + b X$
<u>Initial infiltration rate vs.</u>			
% pore space at 60 cm. water tension	69	0.705** <sup>b</sup>	2.44 + 0.07 X
% pore space at 100 cm. water tension	69	0.721**	2.29 + 0.07 X
% pore space at 1/3 atm. water tension	69	0.711**	1.84 + 0.07 X
<u>Minimum infiltration rate vs.</u>			
Rainfall rate (Marshall only)	10	-0.297	0.33 - 0.05 X
% water stable aggregates > 2 mm.	64	0.081	0.26 + 0.005 X
Air perm. at field cap.	73	0.259* <sup>c</sup>	0.25 + 0.085 X
Air perm. at 60 min.	48	0.308*	0.55 + 0.199 X
Air perm. at 120 min.	43	0.252	0.47 + 0.13 X
% pore space at 60 cm. water tension (mean value of each soil)	6	0.978**	-0.30 + 0.17 X
% pore space at 60 cm. water tension	69	0.882**	-0.22 + 0.15 X
% pore space at 60 cm. water tension (Thurman omitted)	59	0.080	0.29 + 0.009 X
% pore space at 100 cm. water tension	69	0.877**	-0.52 + 0.14 X
% pore space at 1/3 atm. water tension	69	0.788**	-1.31 + 0.14 X
Total pore space	69	-0.651**	7.43 - 0.15 X
Mean weight diameter of aggregates	5	0.044	0.31 + 0.019 X
Dispersion ratio	74	0.091	0.48 + 0.016 X
Dispersion ratio (Thurman omitted)	64	-0.088	0.37 - 0.004 X
<u>Maximum run-off rate vs.</u>			
Rate of rainfall for Marshall	10	0.978**	-0.29 + 1.04 X
Rate of rainfall (all soils)	80	0.229*	0.41 + 0.724 X
Rate of rainfall all soils less Thurman	70	0.793**	-0.70 + 1.094 X

<sup>a</sup>Correlations are for all soils considered together unless noted otherwise.

<sup>b</sup>\*\*Denotes statistical significance at the 1 per cent level.

<sup>c</sup>\*Denotes statistical significance at the 5 per cent level.



Table 15. (Continued)

Physical measurements correlated <sup>a</sup>	Degrees of freedom	Correl. coeff.	Regression equation $\hat{y} = a + b X$
<u>Splash erosion vs.</u>			
% water stable aggregates > 2 mm.	71	-0.264* <sup>b</sup>	6.30 - 0.088 X
Dispersion ratio	81	-0.081	6.51 - 0.036 X
Rainfall intensity	71	0.279*	0.33 + 1.27 X
<u>Wash erosion vs.</u>			
% water stable aggregates > 2 mm.	71	-0.341** <sup>c</sup>	1.01 - 0.02 X
Dispersion ratio	81	-0.168	0.87 - 0.01 X
Rainfall intensity	71	0.307**	-0.18 + 0.25 X
Wash erosion vs. splash erosion	81	-0.206	0.87 - 0.027 X
Minimum wash erosion rates vs. rainfall (Marshall only)	10	0.266	1.25 + 0.18 X
Air perm. at field cap. vs. % pore space at 60 cm. water tension	73	0.192	5.27 + 0.10 X
Air perm. at 60 min. vs. % pore space at 60 cm. water tension	49	0.122	-0.46 + 0.31 X
Air perm. at 120 min. vs. % pore space at 60 cm. water tension	44	0.050	2.01 + 0.016 X

<sup>a</sup>Correlations are for all soils considered together unless noted otherwise.

<sup>b</sup>\* Denotes statistical significance at 5 per cent level.

<sup>c</sup>\*\*Denotes statistical significance at 1 per cent level.

but the correlation with total pore space was negative. Rainfall rate, percentage water stable aggregates  $> 2$  mm., aggregate mean weight diameter, and the dispersion ratio showed no significant relation with the minimum infiltration rate.

Correlations were highly significant at the 1 per cent level for the maximum run-off rate vs. the rate of rainfall for the Marshall soil, and vs. the rate of rainfall for all soils excluding the Thurman. The correlation of the maximum run-off rate with the rate of rainfall for all soils including Thurman was statistically significant at the 5 per cent level.

A highly significant relation at the 1 per cent level was found for the correlation of the initial infiltration rate vs. per cent pore space at 60 cm., 100 cm., and  $1/3$  atmosphere of water tension. In other words there was a close relation between the initial infiltration rate and the percentage of the larger pores which would be open at the field capacity moisture level.

There was no significant relation for the correlation of wash erosion vs. splash erosion, or vs. the dispersion ratio, however the correlation of wash erosion vs. splash erosion although negative was very nearly significant. There was a highly significant negative correlation of wash erosion vs. per cent water stable aggregates  $> 2$  mm. but a positive correlation of wash erosion vs. rainfall intensity. There was not a significant correlation of minimum wash erosion rates with rainfall for the Marshall soil, which had the greatest extremes in rainfall rates. Splash erosion showed a significant negative correlation with per cent water stable aggregates  $> 2$  mm., and a positive correlation with rainfall intensity, but no

correlation with the dispersion ratio.

There was no significant relation between per cent pore space at 60 cm. water tension and air permeability at field capacity or air permeability at 1 and 2 hour intervals after rainfall.

There is an inherent relation among infiltration, run-off, and erosion. For a given amount, or rate of rainfall, the run-off rate will increase as the infiltration rate decreases. With the increased rate and amount of run-off, one would expect an increase in the rate and amount of erosion. Therefore analyses which are significantly correlated with any of these factors would be of value in predicting the relative susceptibility of soils to erosion.

## DISCUSSION

Soil properties in relation to water erosion may be divided into two types: (a) those properties that affect the infiltration rate, or rate with which rainfall enters the soil, and (b) those properties which resist dispersion and erosion during rainfall and run-off.

A summary of the interrelated field and laboratory physical measurements made in this study is given in Table 16. The volume of large pore space present in a soil is one of the important soil properties affecting the infiltration rate. The air permeability measurements made at field capacity (Table 10) and the per cent pores drained by a 60 cm. water column tension in Table 11 are measures of the amount of larger pore space available. From these data it can be seen that the Thurman soil, with the highest infiltration rate and lowest run-off, had the largest percentage of pores drained at 60 cm. of water tension, and was one of the soils with a high air permeability at field capacity. In general, those soils with 3.1 per cent or less of pore space drained at 60 cm. had the lowest minimum infiltration rates and the highest run-off. Air permeability at field capacity of  $5.5\mu^2$  or less was also associated with low infiltration rate and high run-off. The exception to this was the Webster soil which had an air permeability at field capacity of  $3.4\mu^2$ , but had one of the highest minimum infiltration rates and also a large percentage of pores drained at 60 cm.

A tight B horizon several inches below the infiltration cylinder could have retarded the drainage of the larger pores in the Webster soil so that there may have still been many large pores filled with water when the soil was presumably at field capacity. This could have reduced the air permea-

Table 16. Summary of interrelated field and laboratory physical measurements. Field measurements made with a standard rain of 2.01 inches with an intensity of 4.0 in. per hr.  $\pm$  10 per cent delivered by the rainfall simulator. Core samples for water tension measurements taken from  $2\frac{1}{2}$  to  $3\frac{1}{2}$  inch depth. Soil for other laboratory analyses taken from surface  $\frac{1}{2}$  to 1 inch depth.

Soils	Total run-off (in.)	Maximum run-off rate (in./hr.)	Minimum infiltration rate (in./hr.)	Wash erosion (tons/acre)	Splash erosion (tons/acre)	Water stable aggregates > 2 mm. (%)	Dispersion ratio	Silt <sup>a</sup> and clay (%)	Pores drained by 60 cm. water tension (%) <sup>b</sup>	Air perm. at field capacity ( $\mu^2$ )
Webster	1.42	3.40	0.52	0.83	6.50	3.8	7.37	53.0	6.48	3.44
Shelby	1.64	3.65	0.22	0.52	5.97	12.0	10.27	44.3	5.86	6.25
Clarion	1.36	3.32	0.66	0.67	4.47	10.6	14.13	32.0	3.52	7.51
Grundy	1.76	4.05	0.11	0.88	6.18	13.4	15.32	65.5	3.09	5.43
Marshall	1.75	3.90	0.14	1.20	5.79	6.4	16.58	57.4	2.90	5.00
Ida	1.50	3.58	0.43	0.55	3.80	17.0	30.02	35.1	3.32	6.76
Monona	1.76	3.99	0.13	0.90	5.68	5.9	18.42	49.8	1.67	3.60
Thurman	0.18	0.62	3.54	0.03	9.47	0	18.78	6.0	22.41	7.50

<sup>a</sup>  $\leq$  0.02 mm.

<sup>b</sup> Per cent by volume.

bility but still not decrease the water permeability.

Stability of the immediate soil surface is an important property of the soil affecting infiltration and erosion. The percentage water stable aggregates  $> 2$  mm. may be a good indication of how open the soil surface will be for infiltration and resistance to erosion. The Ida, with 17 per cent, had the largest percentage of water stable aggregates and, except for the Thurman, had one of the highest infiltration rates and was one of the lowest soils in wash erosion. Along with the aggregates on the 2mm. sieve for the Ida were a number of root fragments. These along with the high free calcium content of the Ida may have accounted for its measured large number of water stable aggregates.

Soils of this study with less than 6.4 per cent water stable aggregates  $> 2$  mm. were, in general, the soils which had the most wash erosion. Surface sealing, or a tight, compact surface, was observed after rainfall for the Marshall and Monona soils. Air permeability measurements at 1 and 2 hour intervals after rainfall was terminated, confirmed this observation for the soils mentioned. Air permeability measurements 24 hours later might have been better to show surface sealing effects, as more of the large pores should have been drained by then.

The size of the primary particles at the soil surface is another factor affecting infiltration and erosion. In general the greater the sand percentage, the higher the infiltration rate and the lower the runoff and wash erosion. This is well illustrated by the Thurman sand, which had 94 per cent sand  $> 0.02$  mm. and an infiltration rate of 3.54 in. per hr. and only 0.03 tons per acre of wash erosion. The Monona, Marshall, and Grundy, all with 50 per cent or more of silt and clay, had

the lowest infiltration rates and highest run-off and wash erosion.

The dispersion ratio is a measure of the ease with which the silt and clay particles of the soil are dispersed or go into suspension. If the percentage of silt and clay is very small, a high dispersion ratio has little meaning. For example, the Thurman with a dispersion ratio of 18.8 and a total of 5.9 per cent silt and clay, would still have only a very small amount of material in suspension. In this study soils with a dispersion ratio greater than 15 and having 50 per cent or more of silt and clay, were the soils which had the most wash erosion.

Wash erosion as determined by this method seems a better measure of evaluating natural erosion by water than splash erosion or the two combined. Splash erosion would appear to be a possible field method of evaluating the aggregate stability of soil under natural conditions. A high splash erosion value indicates that the soil is easily detachable, but this does not necessarily mean that all the soil detached will be removed. For instance, the Thurman soil with the highest splash erosion had the lowest wash erosion. The reason for this is, of course, that the detached particles were heavy and total run-off was low. Where there is sufficient run-off, a high splash erosion is usually associated with a high wash erosion.

#### Correlations

The correlation studies reported have shown that the infiltration rate is associated with the larger pore spaces which are open at field capacities. This is indicated by the highly significant correlations<sup>1</sup>

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<sup>1</sup>Correlations are positive unless stated otherwise.

of initial and minimum infiltration rate with 60 cm., 100 cm., and  $1/3$  atmosphere water tension values. Air permeability measurements in the field may be of some value in predicting infiltration, as shown by the significant correlations of the minimum infiltration rate with air permeability at field capacity and 60 minutes after rainfall. The air permeability measurements are a reflection of the larger pore spaces open for water, as are the pore spaces at the lower water tensions. The dispersion ratio, mean weight diameter of the aggregates, and percentage water stable aggregates greater than 2 mm., showed no significant relation to the minimum or stable infiltration rate.

During field infiltration determinations it was not always possible to obtain the rainfall rate desired and when the rate exceeded the limits of 4.0 in. per hr.  $\pm$  10 per cent the measurement was completed in the regular manner. The data that differed from 4.0 in. per hr. by 10 per cent or more were used when rainfall intensity was compared with some other measurement. Rainfall extremes varied from 3.13 to 5.74 in. per hr. for the Marshall with the extremes of the other soils falling between these limits. Whenever rainfall intensity was in excess of the infiltration rate of the soil, run-off resulted. Wash erosion, which is closely related to run-off, showed a highly significant correlation with the rate of rainfall for all the soil studied. The maximum run-off rate tended to increase with increased rainfall intensity for all soils studied as shown by the significant positive correlation.

Splash erosion decreased significantly with an increase in percentage of water stable aggregates  $> 2$  mm. and increased with rainfall intensity. Wash erosion decreased significantly with an increase in percentage of



water stable aggregates > 2 mm. and increased highly significantly with rainfall intensity.

### Kinetic Energy of Artificial Raindrops

The rainfall simulator delivers individual drops averaging 5.56 mm. in diameter (Figure 20), based on the weight of individual drops which were caught and weighed. Referring to the data reported by Laws (41), a drop varying from 5 to 6 mm. in diameter has a velocity of 4.3 meters per second for a fall height of one meter. The average weight of the drops delivered was 0.08974 grams. Using this information, the kinetic energy of a raindrop 5.56 mm. in diameter, falling one meter, was calculated to be 8.47 gram centimeters as follows:  $K.E. = \frac{1}{2} MV^2 = \frac{(0.08974) (430 \text{ cm/sec})^2}{2 \times 980} = 8.466 \text{ gram centimeters or } 980 \times 8.466 \text{ gm. cm.} = 8,297 \text{ ergs.}$

Since one cc. of water equals approximately one gram, the 855 cc. of water delivered in 2.01 inches of rainfall equals 1.88 pounds. Assuming that this weight fell as drops averaging 5.56 mm. in diameter, the kinetic energy developed in falling one meter onto the surface area within the infiltration cylinder is calculated to be 80,658 gram centimeters, or 0.41 foot pounds. The kinetic energy developed over the surface area of one acre, for drops 5.56 mm. in diameter falling one meter, is calculated to be 99,039 foot pounds per acre.

The kinetic energy was calculated for several sizes of drops within the range of natural rainfall and is given in Table 17, using data reported by Gunn, taken from a table in an article by Ekern (21).

Figure 20. Drops, produced by rainfall simulator, falling from a height of 18 inches on a wet soil surface. Notice the turbid water in the spray and in the splash developed by two drops upon impact with the surface. Approximately one-fourth actual size.

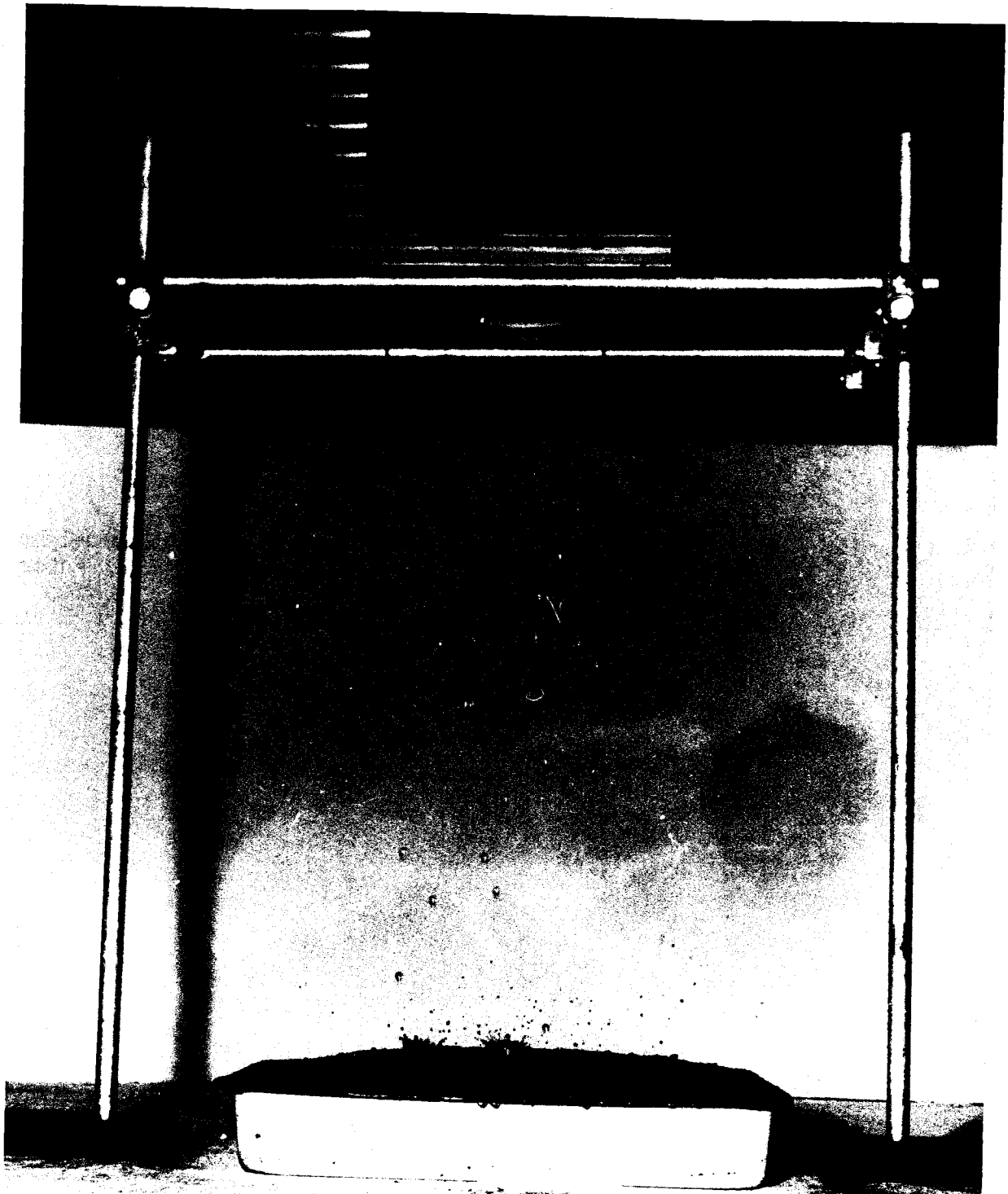


Table 17. Kinetic energy for several sizes of raindrops within the range of natural rainfall, falling at terminal velocity

Diameter of rain drop (mm.)	Kinetic energy (gm. cm.)
1	0.043
2	0.90
3	4.69
4	13.33

The kinetic energy developed by the 5.56 mm. drop of the rainfall simulator falling one meter was 8.47 gm. cm. By interpolation, the energy delivered by the 5.56 mm. drop in its one meter fall would be equivalent to a raindrop of 3.44 mm. falling at terminal velocity. This is in the range of the median diameter drop size for a rain of 4.0 inches per hour intensity, reported by Best, as tabulated in an article by Ekern (21). Therefore this rainfall simulator delivers raindrops which fall with a kinetic energy similar to that produced in a natural rainfall.

#### Erosion Factors and Relative Erodibility

Probably, the most nearly absolute method for studying the erodibility of soils and the effect of cropping practices upon erodibility is by the use of plots where run-off and erosion is measured (so-called control plots). Soil and water losses from natural rainfall are determined under actual field conditions, including the effect of growing vegetation. The inherent disadvantages with run-off control plots are that they are expensive to install, costly to maintain, and records must be maintained over a long period of time to get the desired variations in rainfall intensities.

Browning and co-workers (9) developed a conservation guide for all soils mapped in Iowa. This guide was based on specific data obtained on

run-off control plots for Fayette, Shelby, and Marshall soils as found on the LaCrosse, Wisconsin; Bethany, Missouri; and Clarinda, Iowa soil conservation experimental farms, and "using other physical and chemical information relating these soils to other soils, estimates were made of comparative soil losses of other important soil types in Iowa". The guide was for use in calculating the limit of the slope length for the various combinations of rotations and conservation practices which could be used on Iowa soils. The method of computation was as follows:

1. Select the per cent slope and conservation practice to be used and read the "base slope length" as given in the first table.
2. Select the soil group and crop rotation to be used and read the "rotation-soil factor" as given in the second table.
3. Multiply the base slope length by the rotation-soil factor.

This is the limit of the slope length for this combination of rotation and conservation practice.

If the slope length in the field was less than or equal to the computed slope, the rotation and practice in use were considered as giving adequate protection against erosion.

The base slope length data were calculated from data obtained in field experimental studies. The rotation-soil factor was obtained by multiplying a "soil factor" times a "rotation slope length adjustment factor" which was based on field experimental data. However, the soil factor term was based on actual data for only three soils, the Marshall, Shelby, and Fayette. The soil factor for different soils was computed by multiplying a term called the "soil loss, slope length adjustment factor" times another term called the "permissible soil loss slope adjustment factor". These terms were in turn obtained as a ratio of the soil loss

and the permissible loss of the soil concerned to the Marshall. The reciprocal of each of these ratios was then raised to the  $5/3$  power.

Browning and co-workers (9) divided the soils of Iowa into seven groups and tabulated the rotation-soil factor for eleven crop rotations for all seven groups. The rotation-soil factor as listed by Browning (9 p. 68) for the soils studied in this investigation are shown in Table 18.

Table 18. Browning's rotation-soil factor for the C-C-O-M rotation and the grouping of five of the soils studied.

	Soil Groups						
	A	B	C	D	E	F	G
Rotation-soil factor	0.5	0.4	0.3	0.25	0.2	0.1	0.09
Soils investigated	Marshall <sup>a</sup>	Monona	Clarion	Shelby <sup>b</sup>			
		Ida					

<sup>a</sup>Based on actual measured values on 9 per cent slope Marshall silt loam.

<sup>b</sup>Based on actual measured values on 8 per cent slope but adjusted to 9 per cent slope.

Five of the soils of the present study were listed in four separate groups, in which the rotation-soil factor varied from 0.25 to 0.50.

Thompson (75 p. 317-321) described a method based on Browning's data obtained at Clarinda, by which the loss of soil in tons per acre can be calculated for a soil under various rotations and conservation practices. The answer obtained was compared to the permissible soil losses which were tabulated for various type soils. If the calculated answer exceeded the permissible soil loss, the rotation or conservation practices were changed in such a manner as to reduce the loss to the permissible level. The soil loss is

obtained in this method by multiplying the appropriate value of each of the following factors for the soil concerned: slope per cent, slope length, rotation, degree of erosion, soil erosion or soil factor, soil fertility, and supplemental practice.

The final product is then multiplied by 10, giving the estimated soil erosion loss in tons per acre per year for the soil involved. The soil erosion factor was obtained from a table, presented by Thompson, in which the soils were divided into six groups based on profile characteristics.

The wash and splash erosion data obtained with the rainfall simulator in this investigation, were used to calculate both a rotation-soil factor and a relative erosion factor for each of the eight soils studied. The soils were arranged in groups which differed statistically at the 5 per cent level. The group containing the most soils which did not differ statistically was used as a guide for establishing the group width in tons per acre of erosion. The mean erosion and variance were calculated for this group and these were used to obtain a confidence interval at the 5 per cent level. The difference between the confidence limits obtained was taken as the group width. This value was used to establish groups on either side of the group for which the confidence limits were calculated. Five groups were established for both wash and splash erosion. Rotation-soil factor as calculated by the method of Browning et al.(9), and relative erosion factors were calculated for the limits of each group.

The soil erosion factor for wash erosion was computed as the ratio between wash erosion of the Marshall and that of the soil, or mean of soils, being compared. The soil erosion factor for the splash erosion data was computed as the ratio between the mean splash erosion for the

group which contained the Marshall and the splash erosion for the soil or group of soils being compared.

Rotation-soil factors and soil erosion factors for the wash erosion data are given in Table 19. The five groups of wash erosion varied, by

Table 19. Rotation-soil factor and relative soil erosion factor for soils studied computed from wash erosion data obtained with the rainfall simulator.

	Wash erosion group				
	I	II	III	IV	V
Wash erosion (tons/acre)	<0.25	0.25-0.63	0.63-1.01	1.01-1.39	>1.39
Average wash erosion <sup>1</sup> (tons/acre)	0.03	0.58	0.82	1.20	----
Rotation-soil factor	>7.12	7.12-1.52	1.52-0.69	0.69-0.41	<0.41
Relative soil erosion factor	<0.21	0.21-0.53	0.53-0.84	0.84-1.16	>1.16
Soils studied	Thurman	Shelby, Ida, Clarion	Clarion, Webster, Grundy, Monona	Marshall	----

<sup>1</sup>Average of soils studied in each group.

increments of 0.38 tons per acre, from < 0.25 tons per acre to > 1.39 tons per acre. The soils studied in this investigation were assigned to four of the groups, with no soils of this investigation assigned to group V. Further studies may indicate the necessity of establishing one or more groups having more than 1.39 tons per acre of wash erosion. The rotation-soil factor varied from < 0.41 to > 7.12 and the soil erosion factor from < 0.21 to > 1.16 for the groups set up based on wash erosion data.



The rotation-soil factors and soil erosion factors based on the splash erosion data are given in Table 20. The limits for the splash

Table 20. Rotation-soil factor and relative soil erosion factor for soils studied computed from splash erosion data obtained with the rainfall simulator.

	Splash erosion group				
	I	II	III	IV	V
Splash erosion (tons/acre)	< 2.54	2.54-4.86	4.86-7.18	7.18-9.50	> 9.50
Average splash erosion <sup>1</sup> (tons/acre)	----	4.14	6.02	9.47	-----
Rotation-soil factor	> 2.19	2.19-0.74	0.74-0.39	0.39-0.24	< 0.24
Relative soil erosion factor	< 0.42	0.42-0.81	0.81-1.19	1.19-1.58	> 1.58
Soils studied	----	Ida, Clarion	Monona, Marshall, Shelby, Grundy, Webster	Thurman	-----

<sup>1</sup>Average of soils studied in each group

erosion groups varied from < 2.54 tons per acre to > 9.50 tons per acre.

The soils studied in this investigation were assigned to splash erosion groups II, III, and IV. Future investigations may indicate the need to reduce or increase the number of splash erosion groups. The rotation-soil factor varied from < 0.24 to > 2.19 and the relative erosion factor from < 0.42 to > 1.58 based on the splash erosion data.

The larger the rotation-soil factor or the smaller the erosion factor,

the lower the erodibility of the soil. In this respect the erosion factor is a more obvious indication of erodibility. For both wash and splash erosion, groups were set up which were not occupied by any soils in this study. Additional study is necessary to determine the total number of groups which should be established for all Iowa soils.

The Marshall soil is more erodible than the Shelby, based on the wash erosion data obtained with the rainfall simulator; and based on splash erosion they fall in the same group. The rotation-soil factors reported by Browning, indicated that the Shelby soil was considerably more erodible than the Marshall.

Although the results based on data obtained with the rainfall simulator appear contradictory to Browning's results, both sets of data appear reasonable when the methods are analyzed. Data obtained by the rainfall simulator as used in this study were influenced or affected mainly by a surface layer a few inches thick or less, as the measurements were made over a relatively short time. Based on the dispersion ratio and the percentage silt and clay  $< 0.02$  mm., it can be seen that the Marshall (Table 16) had a higher content of finer material in the surface inch which can be dispersed. As a result of a higher content of fine material there were considerably less large pores drained at 60 cm., which in turn would tend to cause a higher run-off rate. The Marshall did have about 0.1 inch more run-off from two inches of rain than the Shelby. In addition, the lower dispersion ratio, higher percentage of water stable aggregates, and lower percentage of silt and clay  $< 0.02$  mm. for the Shelby indicates that there was less fine material to be washed off of the Shelby. There may also have been considerable variation of soil characteristics

from one location to another.

Browning's data may have been influenced by other factors. The slower rate of rainfall under natural conditions probably allowed water to enter both soils over a considerably longer period of time. When both soils were wetted to the subsoil the differences in subsoil then became the limiting factor. The Shelby, having a slowly permeable subsoil, would start to yield run-off before the Marshall and at a higher rate, since the maximum infiltration could be no greater than the transmission rate of the subsoil. More water running off would have more carrying power and in turn, erosion would increase.

Other factors which might help to explain the differences between the two sets of data are that Browning's results were based on total annual precipitation on an 8 per cent slope and were affected by the seasonal variations and crop cover in addition to the effect of the entire profile. However, the average total rainfall over this period of time varied from 28.3 inches for the Marshall to 32.6 inches for the Fayette. Intensities of rainfall seldom exceeded 4 inches per hour and then only for periods of 5 minutes or less.

Results of other studies indicate that differences may be expected between infiltration measurements made by different methods on the same soil. Musgrave and Free (55), in a comparison of two depths of cultivation, found on the initial run and with a 4 inch depth of cultivation that at the end of 30 minutes the Shelby had an infiltration rate of 2.16 in. per hr. compared to 0.72 in. per hr. for the Marshall. The wet-run 48 hours later, showed an infiltration rate of 0.32 in. per hr. for the Shelby and 0.24 in. per hr. for the Marshall at the end of 15 minutes.

However, at the end of one hour on the wet run the infiltration rate was 0.04 in. per hr. for the Shelby and 0.12 in. per hr. for the Marshall. By this time the subsoil was affecting the infiltration rates more than the top part of the profile. When these soils were cultivated to a depth of 6 inches, the Shelby had an infiltration rate of 1.08 in. per hr. and the Marshall 1.80 in. per hr. at the end of the first 30 minutes of the initial run. At the end of 45 minutes on the wet runs the infiltration rates were 0.04 in. per hr. for the Shelby and 0.16 in. per hr. for the Marshall. The infiltration rate obtained with the rainfall simulator at the end of 15 minutes was 0.28 in. per hr. for the Shelby and 0.02 in. per hr. for the Marshall. The rainfall simulator data at the end of 15 minutes was 88 per cent of the Shelby rate and 83 per cent of the Marshall rate as reported by Musgrave and Free (55) for a wet-run and 4 inch depth of cultivation.

Musgrave (54) reported infiltration data obtained for both Marshall and Shelby on a moist soil which had been in bluegrass sod. The infiltration tubes were installed after the surface vegetation had been removed. Data obtained showed that in the first 15 minutes the infiltration rate of the Marshall silt loam exceeded the Shelby by 0.38 inch. In the first half hour the Marshall exceeded the Shelby by 0.64 inch. Over a period of 6½ hours, the differences in water infiltrated exceeded 3.76 inches. Musgrave also reported that there was from 6.8 to 7.2 times more run-off from the Shelby than the Marshall based on data for continuous corn in control plots.

Musgrave (53) reported infiltration rates for Marshall silt loam in corn plots as varying from 0.71 to 0.75 in. per hr. and direct measure-

ments with an "erosion-type" lysimeter gave a figure of 0.74 inch of water absorbed per hour. The infiltration rate for the Marshall at the end of 25 minutes obtained with the rainfall simulator was 0.14 in. per hr. and a total of 0.28 inch of rain infiltrated in 30 minutes. At the site studied with the rainfall simulator, the estimated maximum rate probably would not have exceeded 0.35 in. per hr. or about 48 per cent of the rate as reported by Musgrave (53).

Smith, Brown, and Russell (72) used Musgrave's infiltrometer to study the effect of organic matter on the infiltration capacity of Clarion loam. Measurements were made in the second year corn of a four year rotation. The total surface inches of infiltration at the end of 30 minutes were as follows: check = 1.03 in., 8 tons manure = 1.44 in., and 16 tons of manure = 1.84 in.

The results obtained on the Clarion with the rainfall simulator in the present study showed an infiltration rate of 0.66 in. per hr. at the end of 25 minutes with a total of 0.65 inch of water infiltrated at the end of 30 minutes. Using these data, the total infiltration for one hour could not have exceeded 0.98 inch. The Clarion of this study was known to have received manure, so that it could probably be compared to the 8 tons of manure treatment. On this basis there was 68 per cent as much infiltration by use of the rainfall simulator.

These results point out some of the differences that may be expected between infiltration measurements made by different methods. The higher infiltration results reported by Musgrave (53) on the Marshall silt loam in second year corn in control plots, of 0.71 to 0.75 in. per hr., as com-

pared to an estimated maximum of 0.33 in. per hr. by the rainfall simulator, might be due to the initial moisture level and soil variation due to location. Since Musgrave's results were obtained on field plots from natural rainfall, it is possible that the soil was initially drier than for the rainfall simulator method. This made more pore space available and the pore spaces were probably larger when dry than when the soil was wet and expanded. The differences between the infiltration results of Smith et al. (72) on the Clarion loam and those by the rainfall simulator could be due to the difference in the method of application. The falling drops tend to both compact the surface by force and disperse the aggregates into smaller particles which plug the pores. Free, Browning, and Musgrave (32) concluded from their investigations that the production of turbid water by the rainfall simulator method was one of the most important factors causing the infiltration rates determined by the "rainfall-simulator" method to be lower than those determined by the tube method.

Erosion data, as obtained by the rainfall simulator are largely a function of the behavior of the surface soil and not of the soil profile. No measurements were taken of the depth reached by the standard rain applied. However, after the rain, when the infiltration cylinders were removed, it was observed that only the Thurman was wetted by the rain through the 6 inch depth of the infiltration cylinder. The rain did not appear to have wetted the other soils more than 2 or 3 inches deep since they had from 1.36 to 1.76 inches of run-off (Table 16). The effect of the soil profile could be brought about by extending the infiltration cylinder so that it penetrated or passed through the B horizon, and by applying rainfall at a lower intensity over a longer period of time.

The rating or grouping of the erodibility of the soils by the method used in this study would appear to be suitable for those times of the year when there is moderate soil moisture present and the rains are of short duration and high intensity. Under these conditions water would not penetrate the soil deep enough to be affected by the B horizon.

The present apparatus could be used to study the effects of surface treatments or conditions on a given soil. Wash erosion results as obtained in this study appear suitable for evaluating the susceptibility to erosion of Iowa soils when the upper profile is moist or wet but drained to essentially field capacity. The preliminary investigations indicated that the apparatus could also be used to obtain more information on soils under field conditions when the soil is dry. Extension of the infiltration cylinder to penetrate the subsoil might improve the usefulness of the apparatus, especially for soils with heavy B horizons.

Splash erosion is a measure of the stability of the soil surface to raindrop impact. Splash erosion is the detached or loosened soil that can be removed. Wash erosion is probably more comparable to erosion as it occurs in the field, since it is a measure of the soil which is easily carried away and put in suspension. Although the Thurman sand was high in splash erosion, the quantity removed as wash erosion was very small. The detached sand particles were heavier than fine soil particles, but the very low wash erosion for the Thurman was a result, primarily, of the fact that there was only a very small amount of run-off to cause wash erosion. Splash erosion might be considered as a good field measurement of aggregate stability similar to McCalla's (49) falling drop laboratory technique.

## SUMMARY

A new type rainfall simulator, used in conjunction with an infiltration cylinder, was constructed and used to make measurements of erosion, run-off and infiltration in the field. The rainfall simulator delivered uniform drops averaging 5.56 mm. in diameter from a height of approximately 1 meter on an area of 167.8 cm.<sup>2</sup>. The kinetic energy delivered by the 5.56 mm. drop in a one meter fall is equivalent to a raindrop of 3.44 mm. falling at terminal velocity, which is in the range of the median diameter drop size for a rain of 4.00 inches per hour intensity.

Infiltration measurements were made with the rainfall simulator on eight Iowa soils under a standard set of conditions so that the only known variables involved were the soils. The soils were Clarion loam, Webster silty clay loam, Thurman loamy fine sand, Marshall silt loam, Ida silt loam, Monona silt loam, Grundy silty clay loam and Shelby loam. All soils studied were in the fall of the oat phase of a C-C-O-M rotation.

Ten plots, 3 x 3 feet, were randomly selected within an area, 9 x 21 feet, on each soil type. The vegetation was clipped at the soil surface within each plot and removed from the area. The brass infiltration cylinder, which was 6 inches in diameter and 6 inches deep, was installed near the center of each plot in such a manner that the soil surface was level. A sheet metal cylinder, 18 inches in diameter and 8 inches deep, and not a part of the rainfall-infiltration equipment proper, was installed to a depth of 4 inches surrounding the infiltration cylinder. The soil area within both cylinders was scratched or cultivated to a depth of about  $\frac{1}{2}$  inch, and pre-soaked so as to be at field capacity at the time of measure-



ment. A total of 2.01 inches of water was applied to each infiltration cylinder by the rainfall simulator at the rate of 4.0 inches per hr. \* 10 per cent. Run-off was caught in a run-off trough which surrounded the infiltration cylinder and which emptied into pint milk bottles. The pint milk bottles were changed at 5 min. intervals throughout the period of rainfall and the samples of run-off water and eroded material collected in them taken to the laboratory for gravimetric determination of the rate and amount of water and soil which ran off. Infiltration was determined as the difference between rainfall and run-off. The run-off samples were also used to determine the rate and total amount of wash erosion caused by the 2.01 inches of rain applied. Splash erosion was determined by collecting and weighing the sediment which remained in the run-off trough at the end of the rainfall.

Several physical measurements were made in the laboratory and field to determine interrelationships among these and soil erodibility. These measurements consisted of air permeability measurements taken just before rainfall, when the soil was at field capacity moisture level, and at several time intervals after rainfall. Core samples were collected from the area next to the infiltration cylinder and moisture tension measurements made. Aggregate stability and dispersion ratio were determined on soil samples collected from the area surrounding the infiltration cylinder.

The results of the supplementary physical measurements indicated that, in general, the following factors were associated with erodible soils: 3.1 per cent or less of pore space drained at 60 cm.; air permeability of  $5.5\mu^2$  or less; 6.4 per cent or less of water stable aggregates  $> 2$  mm.; and 50 per cent or more of silt and clay with a dispersion ratio larger than 15.

Correlations were calculated to determine relationships between the supplementary analyses and infiltration and erosion as determined by the rainfall simulator. Highly significant positive correlations were found between the minimum infiltration rate and per cent pore space drained at 60 cm., 100 cm. and  $1/3$  atmosphere of water tension. No significant relationship was found between the minimum infiltration rate and rainfall rate, dispersion ratio, water stable aggregates  $> 2$  mm., and aggregate mean weight diameter. A significant positive correlation was found between the maximum run-off rate and the rate of rainfall for all soils. When the data for the Thurman soil were omitted, the correlation was highly significant. A highly significant relation was found between the initial infiltration rate and per cent pore space drained by water tension of 60 cm., 100 cm., and 345 cm ( $1/3$  atmosphere).

No statistically significant relation was found between the dispersion ratio and wash erosion, or splash erosion. A highly significant negative correlation was found between wash erosion and percentage water stable aggregates  $> 2$  mm., and a highly significant positive correlation between wash erosion and rainfall intensity.

A significant negative correlation was found between splash erosion and per cent water stable aggregates  $> 2$  mm., and a positive correlation between splash erosion and rainfall intensity.

Based on the minimum wash erosion rate time interval, the eight soils studied could be divided into the following three groups: (1) erosion rate less than 0.1 ton per acre per hour (Thurman); (2) erosion rate varying from 0.95-1.3 tons per acre per hour (Shelby, Ida, and Clarion soils); (3) erosion rate varying from 1.55-2.00 tons per acre per hour (Monona, Grundy, Webster,

and Marshall soils).

Based on total wash erosion the soils were divided into four statistically different groups. The Marshall with 1.20 tons per acre had the most wash erosion for 2.01 inches of rain and the Thurman with 0.03 tons per acre had the least. For both total erosion and splash erosion the soils could only be divided statistically into two groups, composed of Ida and Clarion as the least erodible, with the remaining soils falling into a broader group of higher erosion. The Thurman, although not significantly different from the other soils of the larger group in both splash and total erosion, was considered as a third group of splash and total erosion based on other physical factors.

Browning's rotation-soil factors and the relative soil erosion factors were calculated on the basis of total wash erosion and total splash erosion for the soils studied. Five erosion groups were established for both wash and splash erosion. The soils of this study fell in four of the five groups established for wash erosion and in three of the splash erosion groups. The Thurman soil was in the highest group of splash erosion for either factor and the Marshall in the highest group of wash erosion.

The Marshall soil was found to be more erodible than the Shelby when based on wash erosion data, but based on splash erosion they fell in the same group. The rotation-soil factors reported by Browning indicated that the Shelby was considerably more erodible than the Marshall. These disagreements in the rating of the two soils are due to the different factors affecting the two sets of data. Data obtained by the rainfall simulator were affected mainly by a surface layer several inches thick or less. Browning's data were based on run-off control plots or measurements with

an infiltration cylinder which extended into the B horizon. With either of these types of measurements, the subsoil becomes the limiting factor when its conductivity is less than the infiltration capacity of the surface layer of soil. Other factors which may have helped to account for the differences in the two sets of data are initial moisture content, length of determination, intensity of rainfall and kinetic energy of the raindrops upon impact, seasonal variation, crop cover, and soil variation.

The present rainfall simulator appears to afford a satisfactory method of collecting erosion data for grouping soils for those times of the year when there is moderate soil moisture present and the rains are of short duration and high intensity. The apparatus could be modified to collect erosion data for longer, less intense rains by extending the infiltration cylinder to penetrate the B horizon and reducing the rainfall intensity. The present apparatus could also be used to study the effects of surface treatments or conditions on a given soil.

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APPENDIX A  
DESCRIPTION OF SOILS STUDIED

The following description of soils studied is taken from the unpublished "Established and Tentative Soil Series of the United States" Soil Conservation Service, Division of Soil Survey:

#### CLARION SERIES

The Clarion series includes Prairie soils developed under conditions of good drainage in material derived from friable calcareous glacial till of the Mankato subage of the Wisconsin glaciation, which has a loam or sandy loam texture. They differ from the Carrington soils chiefly in the lesser depth to free carbonates and the lighter texture and slightly brighter color of the subsoil and substratum. Glacial boulders are often scattered over the surface and throughout the soil profile.

- | I. Soil Profile:              | *Clarion loam   | <u>Range:</u> |
|-------------------------------|---|---------------|
| 1. (A <sub>1</sub> ) 0-10"    | Dusky brown loam which has a brownish black color when moist; fine granular structure; slightly acid reaction.  | 8-14"         |
| 2. (A <sub>2</sub> ) 10-18"   | Brownish gray to dark yellowish brown loam, usually having infiltrations of black organic matter from above; slightly acid to neutral.                | 8-10"         |
| 3. (B <sub>2</sub> ) 18-26"   | Moderate to light yellowish brown loam or light textured clay loam; neutral.  | 7-11"         |
| 4. (C <sub>1</sub> ) 26" plus | Light yellowish brown or dusky yellow, light textured clay loam or heavy loam, with abundant yellowish white spots, streaks, and concretions of lime. | 10-12"        |
| 5.                            | Friable calcareous glacial till, light yellowish white to pale yellow when dry. Partly decomposed rock fragments are conspicuous in this horizon.     |               |

- II. Range in characteristics: Chiefly in the depth to lime, which varies from 20 to 30 inches; the texture of the "B" horizon, which ranges from a loam to friable clay loam and the color of the surface soil.

\*Colors according to Misc. Pub. 425, U.S.D.A.

## GRUNDY SERIES

The Grundy series are Prairie soils developed from moderately deep fine textured Peorian loess. These soils occur as associates of Haig soils on slopes that usually range from 2 to 7 per cent. They differ from the Haig soils in having thinner surface horizons and browner subsoils that usually are less mottled. They differ from the Sharpsburg soils, which are developed in somewhat deeper loess, in having more clay in the subsoil and from the Seymour series, developed in somewhat thinner loess, in having less clay in the subsoil. The clay content of the subsoils of the Grundy series ranges from 42 to 50 per cent in the zone of maximum accumulation.

I. Soil Profile: \*Grundy silty clay loam Range:

1. Dusky brown to brownish-black, fine granular light silty clay loam. 8-12" thick
2. Brownish-gray to dark brown silty clay loam splotched and streaked with tongues of darker colors; crushed surfaces have a brownish to dark yellowish-brown color. The upper part of the horizon usually has a fine granular structure, but with depth the granules become larger and more angular. 9-13" thick
3. Moderate olive-brown silty clay mottled with dark orange, strong brown and rust brown iron stains. When broken out the clods fall apart into medium blocky aggregates that are coated with a thin film of dark organic matter. 7-9" thick
4. Light olive-gray, moderate orange, pale olive and weak olive; iron stains and some black; with depth the texture becomes lighter.

- II. Range in Characteristics: The clay content in the "B" horizon varies from about 42 per cent adjacent to the Sharpsburg area to about 50 per cent in the thinner loess adjacent to the Edina area. The surface texture varies from a light silty clay loam to a silt loam. The silt loam texture is usually accompanied by a "B" horizon with a clay content toward the upper limits of the series, while the silty clay loam surface is usually found with a "B" horizon having a clay content toward the lower limits of the series.

\*Colors according to Misc. Pub. 425.

## IDA SERIES

The Ida series include Lithosolic soils developed from deep calcareous loess under the influence of a grass vegetation. They differ from the associated Monona soils in having thinner surface layers, more weakly developed "B" horizons and the presence of carbonates near and occasionally on the surface. They are distinguished from the Hamburg soils chiefly by the presence of a darker surface, a higher percentage of silt and less very fine sand in the upper 10 or 20 inches of the solum and the topography which is rolling to hilly, instead of hilly to steep.

I. Soil Profile: \*\*Ida coarse silt loam\* (Moist) Range:

- |   |        |
|---|--------|
| 1. Weak to dark brown coarse silt loam; neutral to calcareous.  | 0-7"   |
| 2. Strong yellowish-brown coarse silt loam with tongues of weak brown; calcareous with some small concretions.              | 4-6"   |
| 3. Moderate and light yellowish-brown coarse silt loam with some very fine sand; large number of lime concretions.          | 4-7"   |
| 4. Light yellowish-brown coarse silt loam with some yellowish-gray; crushed surfaces have a dusky yellow color; calcareous. | 15-18" |
| 5. Light yellowish-brown silt loam with yellowish-gray and dusky yellow; some iron stains; calcareous with concretions.     | 18-25" |
| 6. Same as above except for more contrasting mottles; calcareous.   |        |

II. Range in characteristics: The thickness and texture of the surface layers and the texture of the "B" horizon; depending largely upon the topography and the distance from the bluffs. The 2 micron clay content for the "B" horizon will vary from 10-20 per cent with a dominant range of 10-15 per cent. The profile is saturated with bases, principally calcium. The content of very fine sand is variable. May include some areas of very fine sandy loam.

\*Formerly recognized as Knox silt loam in western Iowa.

\*\*Colors according to Misc. Pub. 425, U.S.D.A.



## MARSHALL SERIES

Marshall series are Prairie soils developed on uplands from deep, medium textured loess of Peorian age. These soils differ from Tama soils in being more highly saturated with bases, usually growing sweetclover or alfalfa without lime. They differ from the Monona soils, which are developed in deeper loess, in having more clay in the subsoil, and from the Sharpsburg soils, developed in shallower loess, in having less clay in the subsoil. The clay content of the Marshall subsoils ranges from 27 to 35 per cent in the zone of maximum accumulation.

- I. Soil Profile: (Marshall silt loam) Range:
1. (A<sub>1</sub>) 0-12" Dark brown when dry to dusky brown when moist, very friable silt loam; moderately developed fine granular or crumb structure; slightly acid or neutral in reaction. 8-14" thick
  2. (A<sub>3</sub>) 12-16" Weak brown friable silt loam, moderately medium granular structure, very slightly acid to neutral. When the structure particles are crushed the soil is a dark yellowish-brown. 3-6" thick
  3. (B<sub>2</sub>) 18-30" Moderate brown friable silty clay loam; moderately developed fine nuciform structure; very slightly acid to neutral in reaction. When the structure particles are crushed the soil is a moderate yellowish-brown. 10-16" thick
  4. (B<sub>3</sub>) 30-45" Moderate brown friable, heavy silt loam; weakly developed blocky structure; very slightly acid to neutral in reaction. The structure particles crush to a light yellowish-brown. Faint low contrast mottlings may be present below depths of about 35 inches. 10-20" thick
  5. (C) 45" plus Light yellowish-brown or pale brown friable silt loam; no definite structure; neutral in reaction.

II. Range in Characteristics: Chiefly in depth of parent loess, in the lime content of the parent material, in the clay content of the subsoil and the depth to mottlings. In places the parent loess is calcareous below a depth of about 8 feet. The clay content of the Marshall soils varies from about 27

per cent near the Marshall-Monona boundary to about 35 per cent near the Marshall-Sharpsburg boundary. Near the Monona soils the Marshall soils may be free of mottling to a depth of several feet. Near the Sharpsburg soil the Marshall soils usually have some mottlings below about 30 inches.

The nearly level areas of Marshall soils have slightly heavier subsoils and deeper darker colored surface soils than the gently sloping areas. The steeper slopes (over 7 per cent) in the Marshall soil areas have shallower surface soils and in places low contrast mottlings occur in the deeper subsoil.

#### MONONA SERIES

The Monona series includes dark colored Prairie soils developed under a grass vegetation in material derived from deep calcareous loess. They differ from the associated Hamburg and Ida soils in that the "B" horizon shows more development and the carbonates have been leached from the surface and subsoil. They are distinguished from the Marshall soils by having more weakly developed "B" horizons. Monona soils have "B" horizons with from 20 to 27 per cent 2 micron clay, whereas, for Marshall soils the range is about 27 to 35 per cent.

#### I. Soil Profile: \*Monona silt loam (Moist) Range:

- |  |        |
|--|--------|
| 1. Weak to dusky-brown, slightly acid silt loam.   | 7-9"   |
| 2. Dark-brown to dark yellowish-brown, slightly acid silt loam, slightly heavier than the surface.   | 6-9"   |
| 3. Dark to moderate yellowish-brown silt loam, neutral reaction.   | 15-18" |
| 4. Light yellowish-brown silt loam, low contrast mottles of strong brown and pale olive.   | 5-40"  |
| 5. Moderate to light yellowish-brown mildly alkaline silt loam; usually enough calcium carbonate present to effervesce when treated with dilute hydrochloric acid. |        |

II. Range in Characteristics: The thickness of the surface layer varies from a total of 7 to 10 inches; the texture of the subsoil ranges from a coarse silt loam to a heavy silt loam; the depth to carbonates is somewhat variable, depending upon relief and degree of erosion.

\*Colors according to Misc. Pub. 425, U.S.D.A.

## SHELBY SERIES

The soils of the Shelby series include Prairie soils, which are typically developed on deeply weathered Kansan and Nebraskan till. They usually occur on slopes and narrow ridge crests and the parent material exposed on the slopes in many locations includes successive layers of unleached and moderately leached glacial drift modified occasionally by material slumped down from the overlying loessial deposits, which blanket the flats above the Shelby areas. Seams of secondary lime occur locally but usually at  $3\frac{1}{2}$  to 4 feet below the surface. The Shelby soils differ from the Carrington soils of the Iowan drift sheet in having a thinner solum and heavier textured "B" horizon and from the Lagonda soils in that the surface horizon is thinner and the "B" horizon not so tough and heavy and yellowish-brown rather than brownish-gray or gray. The principal difference between these soils and the Lindley soils is the darker color of the surface layers. These soils have an acid reaction at all depths except for seams of secondary lime below about 40 inches.

## I. Soil Profile: \*Shelby loam

1. Weak brown to dusky brown loam; 6 to 8 inches thick.
2. Weak brown fine granular loam with tongues and splotches of dark yellowish-brown; 3 to 5 inches thick.
3. Moderate yellowish-brown clay loam with some fine and medium sized glacial rocks; 6 to 8 inches thick.
4. Moderate yellowish-brown gritty clay to clay loam with low contrast mottles of brownish-gray, light yellowish-brown and iron stains; fragments of disintegrated glacial boulders usually granites and schists.
5. Moderate yellowish-brown gritty clay mottled with gray, rust brown and light and dark yellowish-brown; disintegrated glacial boulders; occasionally the entire mass is a mixture of sand, gravel and boulders held together by clay.

II. Variations: The thickness of the dark colored surface layer, which may range from 6 to 12 inches; usually depends upon the rapidity with which it is removed by erosion and on the extent to which dark sediments are accumulating from higher land. Considerable variation also arises from the differences in the character of the parent material particularly in the proportion of coarse sand, gravel and boulders. As stated above, some secondary lime occurs as seams or along old root channels, but usually at depths of  $3\frac{1}{2}$  to 4 feet below the surface. Horizons 4 and 5 may occasionally be free of mottling.

\*Colors according to Misc. Pub. 425, U.S.D.A.

## THURMAN SERIES

Soils of the Thurman series have developed under the influence of grass vegetation from materials composed largely of loose sand with a small admixture of silt. They have darker and more stable surface layers than occur in the soils of the Valentine series, and differ from the Dickinson soils, which have developed over more or less reworked sandy drift, in having less coherent upper subsoil layers. The transition between the different horizons is very gradual in both color and texture. There is no structure development in any part of the profile. The soils are thoroughly leached of their lime.

## I. Soil Profile: \*Thurman loamy fine sand

1. Dusky-brown (moist) to weak brown (dry) friable, slightly coherent loamy fine sand, from 8 to 14 inches thick.
2. Transition layer of light brownish-gray loamy fine sand; 7 to 12 inches thick.
3. Dark yellowish-brown to moderate yellowish-brown incoherent sand.

II. Range in Characteristics: The dark-colored surface soil varies in thickness in proportion to erosion by wind and water. Erosion, however, is not rapid, on virgin areas, and the soils are fairly uniform. Under poor management, the cultivated soil loses its stability and serious damage may result from wind erosion. Locally, the soils may contain a small amount of gravel.

\*Colors according to Misc. Pub. 425, U.S.D.A.

## WEBSTER SERIES

The Webster series includes intrazonal soils within the Prairie region, which have developed over friable glacial till, of the Mankato subage of the Wisconsin glaciation, which has a loam to sandy loam texture. The Webster series includes the imperfectly and poorly drained members of the Clarion-Storden catena of soils. Glacial pebbles, stones and boulders occur on the surface and throughout the soil. They are distinguished from the Glencoe soils by the thinner dark colored surface layers, the lighter texture and color of the substratum and the presence of larger amounts of sand and gravel in the subsoil and substratum.

## I. Soil Profile: \*Webster silty clay loam

Range:

1. Brownish-black (moist) to dusky brown (dry)

silty clay loam, slightly acid to neutral; fine to medium granular structure.

8-12"

2. Brownish-black (moist) silty clay loam to light clay loam, very fine angular blocky structure; slightly acid to neutral.

7-9"

3. Medium olive gray light clay loam to heavy silty clay loam with mottles of weak olive, pale olive and light olive gray; some fine glacial material in lower part; neutral reaction.

7-10"

4. Weak to pale olive gritty light clay loam to heavy loam mottled with shades of olive and olive gray; neutral to calcareous.

8-10"

5. Light olive gray friable loam with mottles of pale olive, weak olive, dusky yellow and medium olive gray; calcareous; glacial fragments and spots and concretions of lime.

II. Range in Characteristics: Surface textures range from loams to silty clays and subsoils from heavy loams to heavy clay loams. Depth to lime and the light olive gray parent material is also quite variable and the range is 20 to 35 inches.

\*Colors according to Misc. Publ 425, U.S.D.A.

**APPENDIX B**

**AIR PERMEABILITY CORRECTIONS**

## Appendix B

Air permeability was calculated in absolute units ( $\mu^2$ ) by the following equation as given by Grover (35):  $v/t = KA\Delta p/\eta$ . In which "V" = volume (cc.) of air forced into the soil in time t (Sec),  $\Delta p$  is the gauge pressure of the air (dynes/cm<sup>2</sup>) in the air chamber,  $\eta$  is the viscosity (poise) of the air, and A (cm.) is a constant which depends on the geometry of the air flow boundaries in the soil".

$$A = 13.68 \text{ cm.}$$

$$\Delta P \text{ large float} = 3.18 \text{ cm.} \times 980 = 3116 \text{ dynes/cm.}$$

$$\Delta P \text{ small float} = 3.34 \text{ cm.} \times 980 = 3273 \text{ dynes/cm.}$$

V and t were determined for each measurement and recorded.

$\eta$ , or the viscosity of the air, was determined for 95 per cent relative humidity, as suggested by Grover (35), and the temperature recorded at the time of measurement.

Buehrer (10), in figures which he plotted, showed the effect of temperature and relative humidity on the viscosity of air. His figures showed that the viscosity of dry air increased with temperature from 0° C. to 40° C. and that the viscosity of air at 25° C. decreased as the relative humidity increased from 0 to 100 per cent. Buehrer concluded that the temperature effect was so small that it could be neglected. However, he found by experimentation that the effect of humidity increased the flow rate 58 per cent from 0 to 100 per cent relative humidity at about 25° C.

In order to obtain the viscosity of the air at 95 per cent relative humidity over the range of temperatures at which measurements were made, it was necessary to composite data from Meyer and Anderson (50, p. 160) and Buehrer (10). The relation between vapor pressure and temperature at

95 per cent relative humidity is shown in Figure 21, and was taken from data by Meyer and Anderson (50, 6. 160). The variation of viscosity and vapor pressure of air with relative humidity at 25° C. is given in Table 21.

Table 21. Variation of viscosity and vapor pressure of air with relative humidity at 25° C.

Relative humidity (per cent)	Viscosity <sup>a</sup> (absolute units)	Vapor <sup>b</sup> pressure (mm. Hg.)
0	0.0001826	0
10	0.0001732	2.38
20	0.0001658	4.75
30	0.0001584	7.13
40	0.0001513	9.50
50	0.0001453	11.88
60	0.0001395	14.26
70	0.0001337	16.63
80	0.0001284	19.01
90	0.0001232	21.38
100	0.0001184	23.76

<sup>a</sup>Taken from Buehrer (10) Figure 11. Variation of viscosity of air with temperature and humidity.

<sup>b</sup>Taken from Meyer and Anderson (50, p. 160) Table 15. The relation between relative humidity and vapor pressure at different temperatures.

Figure 22, showing the relation between vapor pressure and air viscosity at 25° C., was plotted from the data in Table 21. Table 22, showing the vapor pressure and viscosity of humid air at different temperatures, was tabulated from data taken from Figures 21 and 22. The viscosity of the air at 95 per cent relative humidity and the recorded field temperature was then read directly from Table 22.



Figure 21. Relation between vapor pressure (mm. Hg.) and temperature ( $^{\circ}\text{C}$ ) at 95 per cent relative humidity.

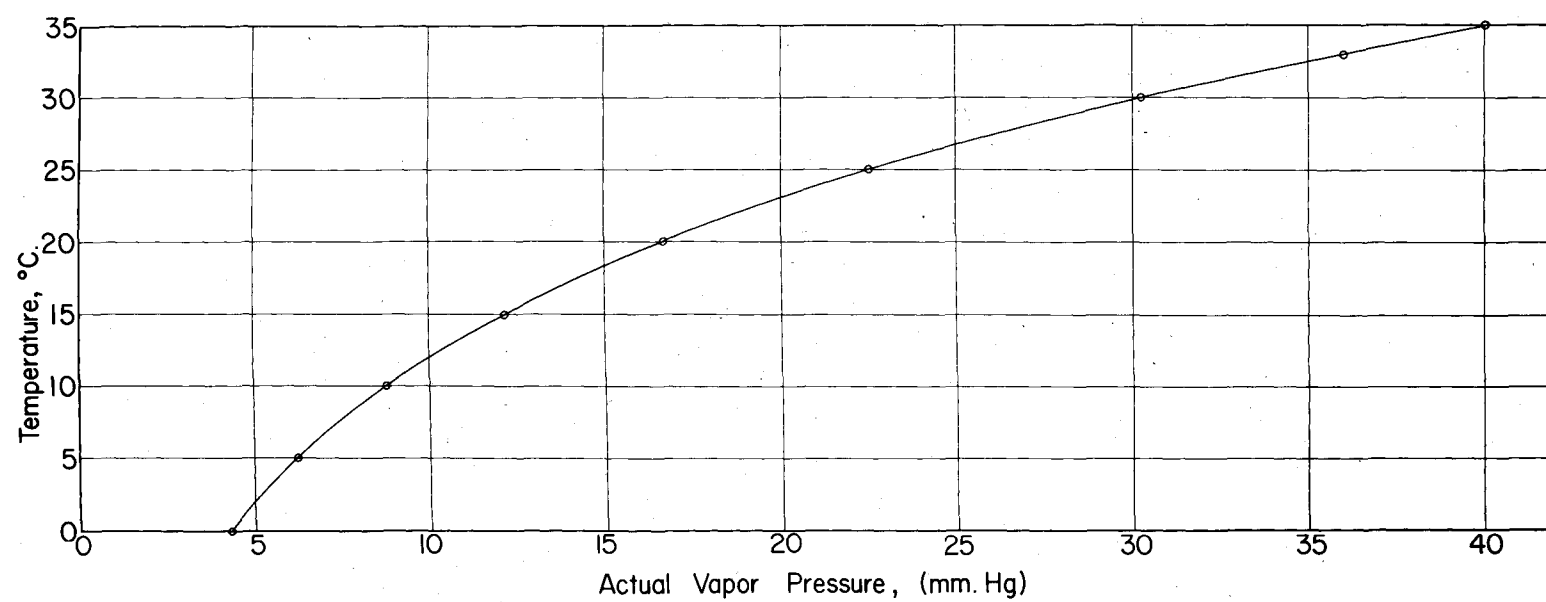


Figure 22. Relation between vapor pressure (mm. Hg.) and air viscosity (absolute units) at 25° C. Vapor pressure data taken from Table 15, Meyer and Anderson (50, p. 160). Viscosity data taken from Figure 11, Buehrer (10, p. 48).

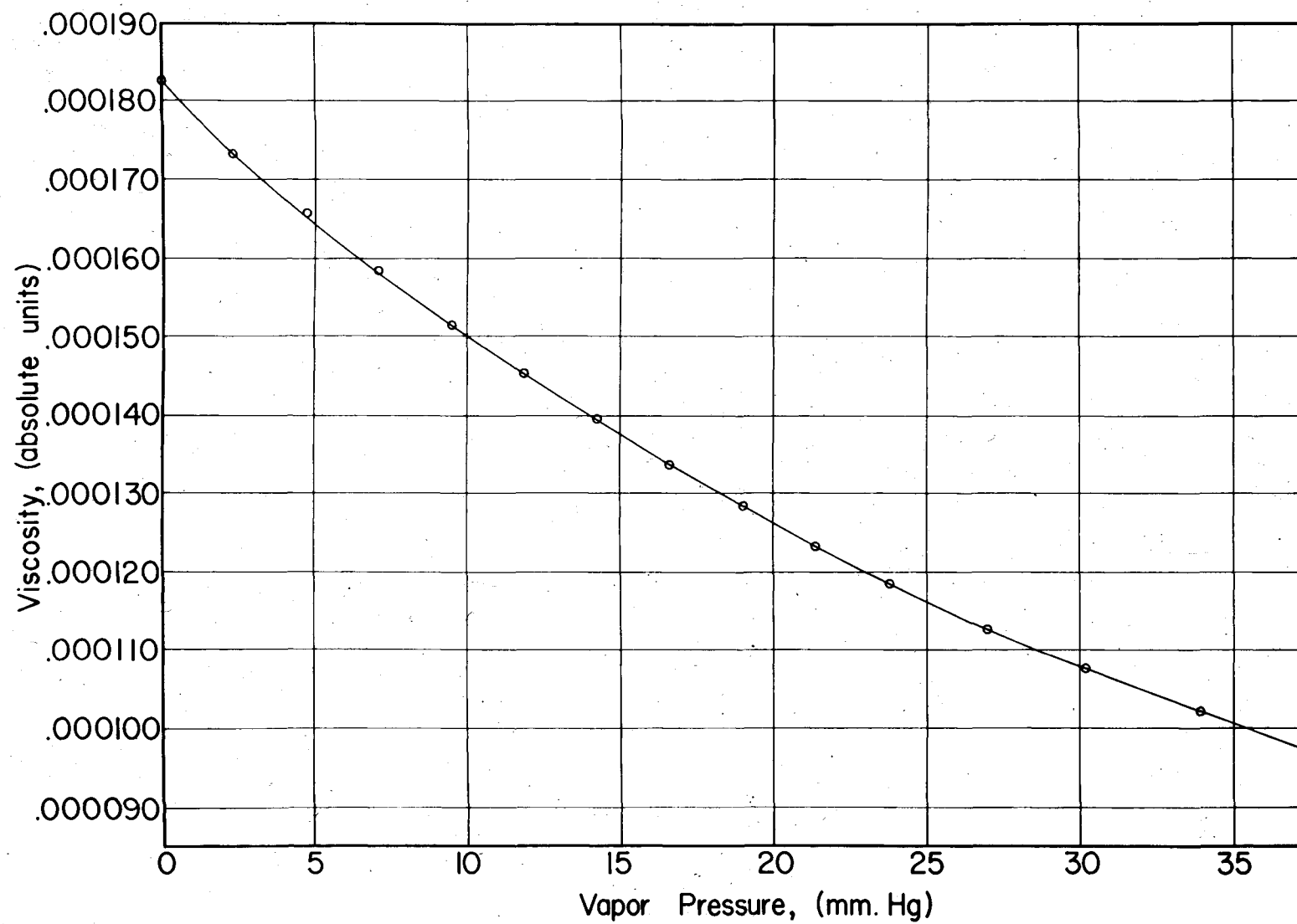


Table 22. The vapor pressure and viscosity of humid air at different temperatures.

Temp. °C	Vapor pressure (mm. Hg.)	Viscosity	Temp. °C	Vapor pressure (mm. Hg.)	Viscosity
0	4.3	0.000167	18	14.7	0.000138
1	4.7	0.000165	19	15.6	0.000136
2	5.0	0.000164	20	16.6	0.000134
3	5.4	0.000163	21	17.6	0.000131
4	5.8	0.000162	22	18.7	0.000129
5	6.2	0.000161	23	19.9	0.000126
6	6.7	0.000159	24	21.2	0.000123
7	7.1	0.000158	25	22.5	0.000121
8	7.6	0.000157	26	23.9	0.000118
9	8.2	0.000155	27	25.4	0.000115
10	8.7	0.000154	28	27.0	0.000113
11	9.4	0.000152	29	28.5	0.000110
12	10.0	0.000150	30	30.2	0.000107
13	10.7	0.000148	31	32.0	0.000105
14	11.4	0.000146	32	33.9	0.000102
15	12.2	0.000144	33	35.9	0.000099
16	13.0	0.000142	34	38.0	0.000096
17	13.8	0.000141	35	40.1	0.000093

<sup>a</sup>Relative humidity of 95 per cent.